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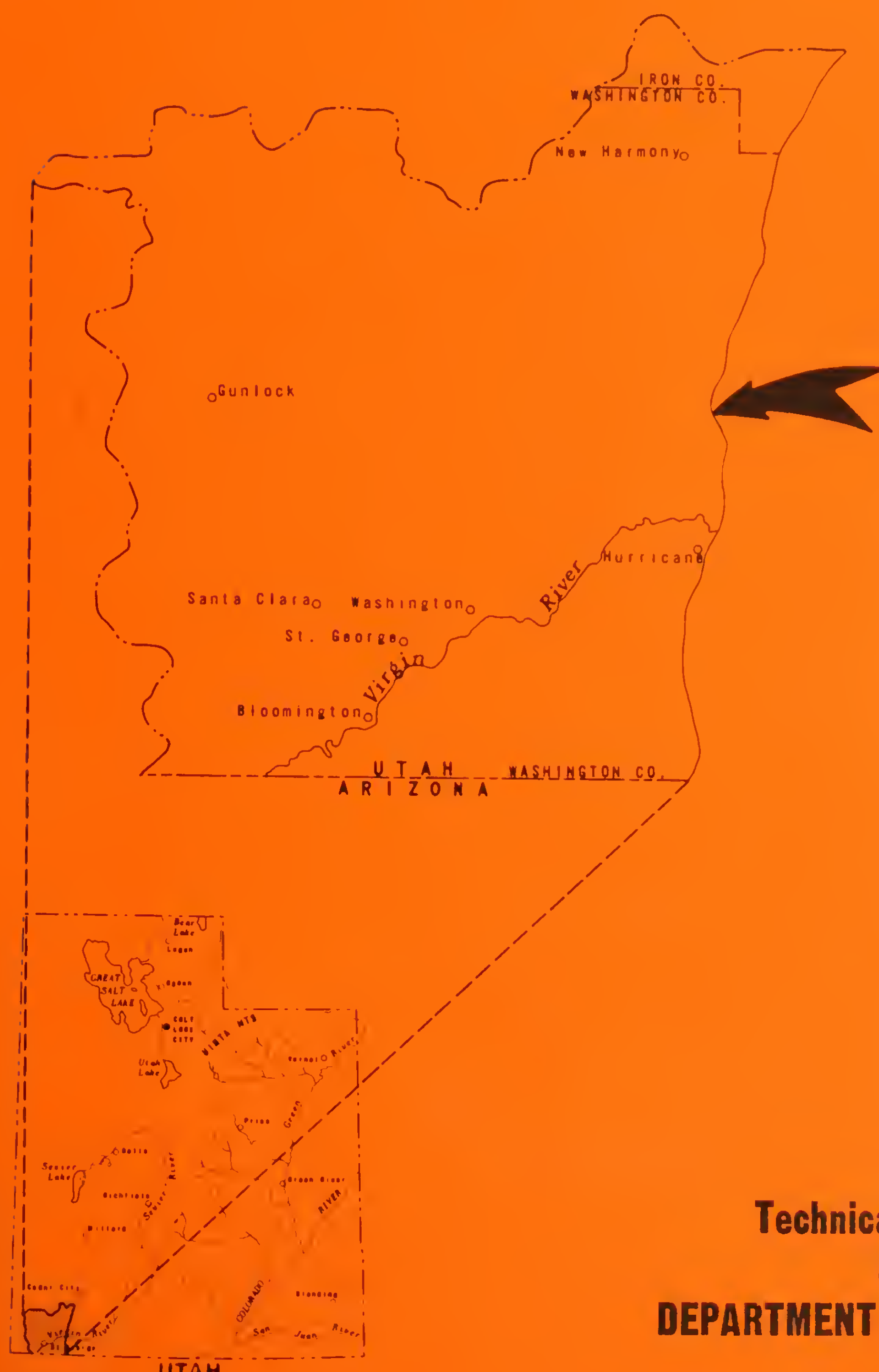
GROUND-WATER CONDITIONS IN THE NAVAJO SANDSTONE IN THE CENTRAL VIRGIN RIVER BASIN, UTAH



CENTRAL VIRGIN RIVER BASIN

Technical Publication No. 61
State of Utah
DEPARTMENT OF NATURAL RESOURCES
1978

SCOTT M. MATHESON
Governor

This report was prepared as a part of the Statewide cooperative water-resource investigation program administered jointly by the Utah Department of Natural Resources, Division of Water Rights and the United States Geological Survey. The program is conducted to meet the water administration and water-resource data needs of the State, as well as the water information needs of many units of government and the general public.

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STATE OF UTAH
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by

R. M. Cordova, Hydrologist
U.S. Geological Survey

Prepared by
the United States Geological Survey
in cooperation with
the Utah Department of Natural Resources
Division of Water Rights

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ENGLISH-TO-METRIC CONVERSION FACTORS

Most values in this report are given in English units followed by metric units. The conversion factors used are shown to four significant figures. In the text, however, the metric equivalents are shown only to the number of significant figures consistent with the accuracy of the value in English units.

English Unit (Multiply)	English Abbreviation	(by)	Metric Unit (to obtain)	Metric Abbreviation
Acre		0.4047	Square hectometer	hm^2
Acre-foot	acre-ft	.001233	Cubic hectometer	hm^3
Foot	ft	.3048	Meter	m
Foot per mile	ft/mi	.1894	Meter per kilometer	m/km
Gallon per minute	gal/min	.06309	Liter per second	L/s
Gallon per minute per foot	(gal/min)/ft	.2070	Liter per second per meter	(L/s)/m
Inch	in.	25.40	Millimeter	mm
Mile	mi	1.609	Kilometer	km
Square foot	ft^2	.0929	Square meter	m^2
Square mile	mi^2	2.590	Square kilometer	km^2

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in the English unit, parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to the English unit, equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: $°F = 1.8(°C) + 32$.

GROUND-WATER CONDITIONS IN THE NAVAJO SANDSTONE IN THE CENTRAL VIRGIN RIVER BASIN, UTAH

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ABSTRACT

The central Virgin River basin, Utah, includes about 1,000 square miles (2,600 square kilometers) in the drainage basin of the Virgin River downstream from the Hurricane Cliffs. The Navajo Sandstone of Late Triassic(?) and Jurassic age crops out in 234 square miles (606 square kilometers) of the basin and underlies younger rocks in about 450 square miles (1,200 square kilometers) of the basin.

Lithologically, the Navajo Sandstone is essentially a quartzose sandstone, about 2,000 feet (600 meters) in maximum thickness, comprising three distinct units denominated the lower, middle, and upper units. The Navajo is practically homogeneous in size and sorting of its grains.

Recharge to the Navajo Sandstone is estimated for 1974 to be a minimum of 17,000 acre-feet (21 cubic hectometers) and is by the (1) infiltration of precipitation directly on the outcrop, (2) infiltration of streamflow in the outcrop area, (3) infiltration of water from the overlying Carmel Formation, and (4) the inflow of ground water from outside the project area.

Movement of ground water is generally from the Pine Valley Mountains, Bull Valley Mountains, and the area east of the Hurricane Cliffs toward the Virgin River and its tributaries. The overall direction of ground-water movement is independent of the strike or plunge of the large structural features; joints, where open, have a strong influence on the local direction of flow. Geologic fieldwork in the project area inferred that some faults are impermeable at depth. Faults in some cases are identifiable in the field by what has been termed for this study, a trellis zone, which is a narrow, linear zone consisting of complexly intersecting fractures filled with siliceous cement.

Discharge of ground water in 1974 amounted to a minimum of 19,000 acre-feet (23 cubic hectometers). Discharge is by (1) seepage into streams, (2) springs, (3) percolation into the Kayenta Formation, (4) wells, and (5) evapotranspiration. Discharge from wells in 1974 was 2,300 acre-feet (2.8 cubic hectometers). The discharge rate of wells averages about 540 gallons per minute (34 liters per second); the average specific capacity for a 24-hour period is 16 gallons per minute per foot (3.3 liters per second per meter) of drawdown.

The average effective porosity in the saturated zone is estimated to be 17 percent based on laboratory analysis of rock samples and total porosity is 32 percent based on borehole techniques using resistivity and neutron logs. The hydraulic conductivity has an average value of 2.1 feet per day (0.64 meter per day) based on laboratory analysis, but the average value is 5 feet per day (1.5 meters per day) based on field tests.

Changes in storage in the Navajo Sandstone of the basin are controlled mainly by precipitation and well discharge. A significant long-term change in storage has not occurred in a large part of the area. However, a decrease in storage has occurred at St. George City's Gunlock well field. The maximum amount of ground water in storage available to wells is estimated to be 2.8 million acre-feet (3,450 cubic hectometers).

The hydrologic effects of wells discharging from the Navajo Sandstone in the basin include interference between wells and reduction of streamflow.

Chemical analysis of the water in storage indicates that the concentration of dissolved solids and of the principal ions ranges widely; for example, the dissolved solids range from 103 to 1,360 milligrams per liter. Water percolating in the lower unit and along fault zones has the largest amount of dissolved minerals. Bicarbonate water is the most common type; sulfate and mixed waters are fairly common. The sulfate ion dominates or generally is in significant amounts in ground water that is from the lower unit or is moving along or near a fault; the chloride ion is in significant amounts in ground water moving along or near some faults.

The temperature of ground water ranges from 11.0° to 40.0° Celsius. One reason for the large range is the effect of altitude, lower temperatures being at higher altitudes. Another reason is the normal increase of temperature with an increase of depth to water. The average increase of temperature with depth in the saturated zone is 0.56° Celsius per 100 feet (30 meters).

The Navajo Sandstone in the central Virgin River basin has a favorable potential for additional development by large-discharge wells. In most localities in which wells have reached the saturated zone, discharge rates, specific capacities, and chemical quality have been satisfactory for such development. The main factors limiting the potential for development include storage, recharge, and effects of pumping; locally water quality and temperature are added limiting factors.

INTRODUCTION

Purpose and scope

The increased need for water in southern Utah for municipal and industrial purposes has prompted water users to look to the ground-water reservoir for additional supplies. Experience gained by water-well users during the exploration for water supplies indicated that the Navajo Sandstone was a source of ground water that had a greater promise for large yields and good quality water than any other consolidated-rock formation. However, little basic hydrologic data and no overall hydrologic evaluation of the formation were available to aid the Utah State Engineer in determining whether large-scale development would be feasible. Consequently, the State Engineer requested the U.S. Geological Survey, as part of the Statewide cooperative agreement with the Utah Department of Natural Resources, to make a study of the hydrogeology of the Navajo Sandstone in the central Virgin River basin where wells in the formation are more numerous than in other places.

This investigation of the Navajo Sandstone (pl. 1) was begun July 1, 1973, and was completed June 30, 1976. Detailed information was obtained on recharge, movement, discharge, storage, utilization, chemical quality, and temperature of the ground water. The interpretation of the hydrogeology of the Navajo is confined to the outcrop area as shown in figure 1 because of a lack of hydrologic data and sparse geologic data on the formation outside this area.

Previous studies and acknowledgments

Interpretive hydrogeologic studies in the central Virgin River basin have not been made exclusively of the Navajo Sandstone. A study of the ground-water conditions of the central Virgin River basin by Cordova, Sandberg, and McConkie (1972) contains some data and interpretive information for the Navajo.

Studies of the basin geology have been made by several geologists, but none of these studies was confined to the Navajo Sandstone. Previous geologic studies used for this investigation include those by Cook (1960), McCarthy (1958), Reber (1951), and Wiley (1963).

Thanks are extended to all the residents of the project area who facilitated the progress of the investigation. Particular appreciation is extended to Messrs. Rudger McArthur and Glenn Gubler, city officials of St. George, to Mr. Wayne Wilson of LaVerkin, and to Mr. Frank Sullivan of Washington.

Geographic setting

Location, physiography, and drainage

The central Virgin River basin includes about 1,000 mi^2 (2,600 km^2) in the drainage basin of the Virgin River downstream from Hurricane Cliffs (pl. 1). The Navajo Sandstone crops out in about 23 percent of the basin.

Most of the basin is characterized by post-Paleozoic sedimentary formations with generally low angles of dip, prominent escarpments, and youthful drainage. West of St. George, however, the sedimentary formations are steeply upturned on the flanks of the Beaver Dam Mountains--a strongly faulted and folded range of Paleozoic and pre-Paleozoic rocks. Altitudes above mean sea level range from about 2,400 ft (730 m) where the Virgin River flows into Arizona to about 10,300 ft (3,100 m) in the Pine Valley Mountains.

Drainage is by the Virgin River and its tributaries, which are part of the Colorado system. The Virgin River is perennial, and its tributaries are perennial, intermittent, or ephemeral.

Climate

The climate of the project area is generally characterized by a small amount of precipitation, mild winters, hot summers, and a high rate of evaporation. The areal distribution of precipitation is shown on plate 1.

The largest amounts of precipitation generally fall during December, January, February, and March, but significant amounts also fall during the summer. In the winter, precipitation is commonly snow in the mountains and rain at lower altitudes; but in the summer, precipitation is commonly in the form of torrential rainstorms and runoff is rapid. The winter precipitation therefore probably contributes the greatest amount of recharge to the ground-water reservoir.

Average monthly temperatures at low altitudes are usually above freezing in the winter and exceed 80°F (26.5°C) in July and August. The annual amount of pan evaporation at St. George, based on studies by the U.S. Bureau of Reclamation (oral commun., 1968) is about 89 in. (2,260 mm). The estimated evaporation from a free-water surface at St. George therefore, using a pan coefficient of 0.70, is about 62 in. (1,600 mm).

Culture and economy

Mormon pioneers established the first settlement, in the New Harmony area, in 1852; most of the present communities were settled by 1905. St. George, the largest community in the project area, was settled in 1861 and is the county seat of Washington.

Agriculture forms the economic base, but a large part of the income is derived from tourism. Irrigation is necessary for the success of agriculture in the area, and about 17,000 acres (6,900 hm^2) of land is irrigated. The main irrigated crops are small grains, fruits, vegetables, and sugar beet seed. Ground water is a supplementary source of irrigation supply during periods of low streamflow. Ground water is a principal source of municipal supply, and the city of St. George pumps four large-discharge wells in the Navajo Sandstone and is prospecting for more well sites.

Numbering system for hydrogeologic-data sites

The system of numbering hydrogeologic-data sites (wells, springs, etc.) in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres (4 hm^2);[1] the letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre (4-hm^2) tract; the letter S preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted. Thus (C-41-17)17 cba-1 designates the first well constructed or visited in the NE¼NW¼SW¼ sec. 17, T. 41 S., R. 17 W., and (C-42-15)10a-S1 designates a spring known only to be in the NE¼ sec. 10, T. 42 S., R. 15 W. Other sites where hydrogeologic data were collected are numbered in the same manner, but no serial number is used. The numbering system is illustrated in figure 1.

GEOLOGY

Age, areal extent, and thickness

The Navajo Sandstone is considered to be of Late Triassic(?) age in its lower part and Jurassic age in its upper part (Lewis and others, 1961). Outside the project area these age designations are based on fossils and on an intertonguing relation with the stratigraphically older Kayenta Formation (Triassic) and the younger Carmel Formation (Jurassic). However, neither fossils nor an intertonguing relation have been found in the project area.

Plate 1 shows the area of outcrop to be concentrated in an arcuate belt across the middle of the basin and in the southeastern part of the basin. The formation crops out in 234 mi^2 (606 km^2) of the basin and underlies younger rocks in about 450 mi^2 (1,200 km^2) of the basin in its northern and eastern parts.

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[1]Although the basic land unit, the section, is theoretically 1 mi^2 (2.6 km^2), many sections are irregular. Such sections are subdivided into 10-acre (4-hm^2) tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

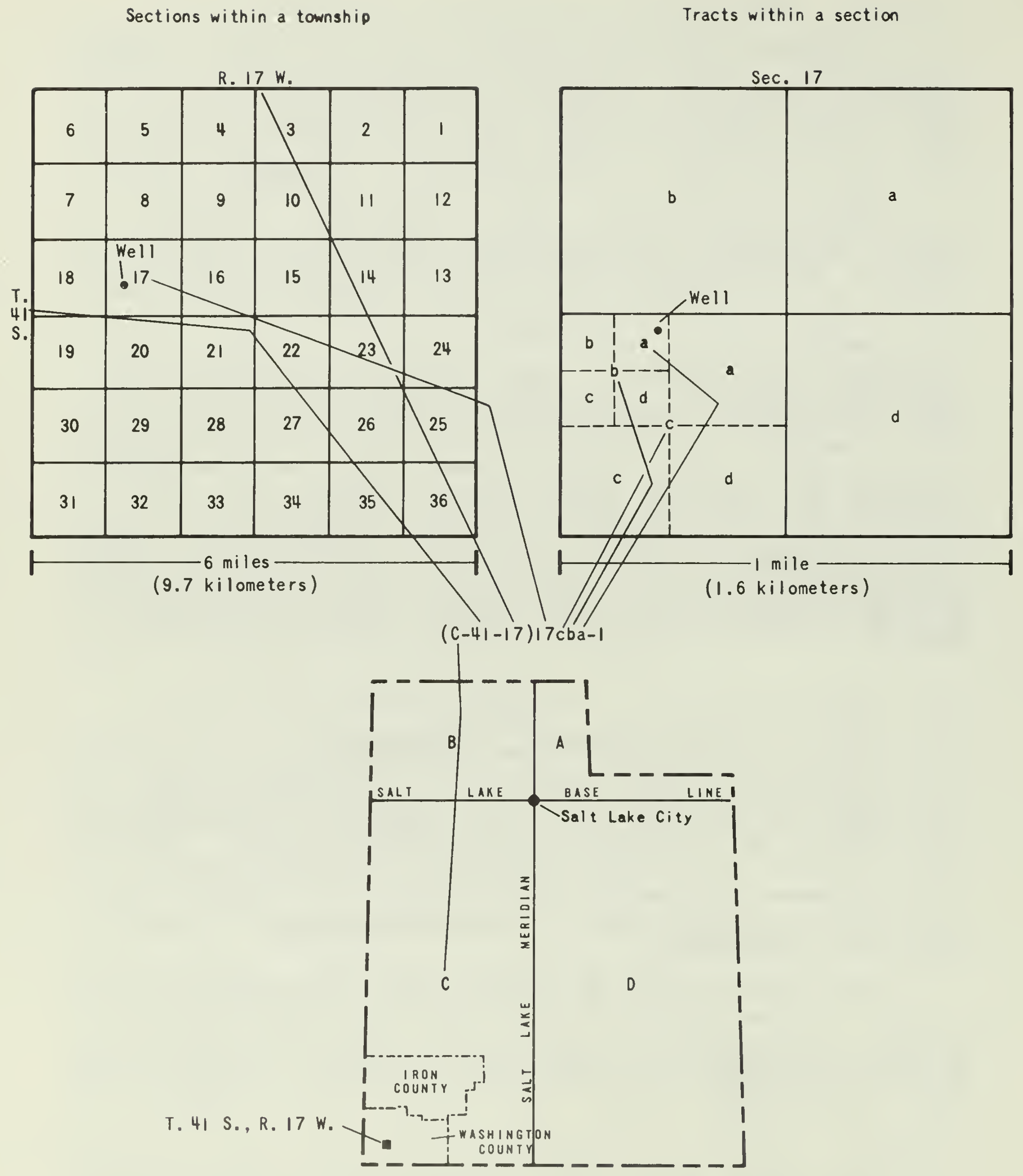


Figure 1.— Numbering system for hydrogeologic-data sites in Utah.

The thickness of the Navajo Sandstone in the outcrop area ranges from about 0 to about 2,000 ft (600 m) (pl. 2). The thickness was determined by projecting the formation's basal contact, where known, into the subsurface and then subtracting the altitude of the basal contact from the altitude of the land surface vertically above the contact at many points. These points were generally distributed in a quadrilateral network with 0.5- to 2-mi (0.8 to 3.2 km) spacings, which gave a fairly even and geometric distribution. The generally low stratigraphic dips (5° or less) allowed the subtraction to be done without correction for dip in most localities and without significant error. This method was used because only a few deep wells and test holes are available as control points for determining the altitude of the base of the formation. Therefore, this method has inherent error because there is practically no subsurface control and because a constant dip is assumed in the subsurface; such changes undoubtedly occur where there is folding, faulting, or variations in formational thickness. Therefore, the resulting lines of equal thickness are generalized and do not indicate exact thicknesses for particular localities. This is especially true for localities where the topography is deeply incised by stream channels; in such areas the error may be on the order of several hundred feet.

Lithology

The Navajo Sandstone is essentially a quartzose sandstone with a minor amount of accessory minerals, generally bound by calcareous cement and locally by silica. Individual quartz grains are characterized by a high degree of rounding and a frosted surface. A thin-section study was made of the formation in the Gunlock area by Johnson (1972), and the following information on mineral content is abstracted from his report:

Mineral	Range (percent)
Quartz	72-88
Chert, clay, rock fragments	1.6-16.9
Calcite	0-14
Feldspar (orthoclase and microcline)	0.9-9.6
Heavy minerals (zircon, tourmaline, iron oxides, garnet)	0-5.5

The Navajo Sandstone comprises three distinct lithologic units, which are denominated in this report as the lower, middle, and upper units.

The lower unit comprises reddish brown (10R4/6),[1] mainly very fine to fine-grained, firmly cemented sandstone, some moderate reddish

[1]Color system of the Rock-Color Chart Committee (Geological Society of America, 1970).

orange (10R6/6) fine- to medium-grained sandstone, and reddish brown (10R4/6) mudstone and siltstone. The unit has a maximum thickness of about 100 ft (30 m).

Separating the typical Navajo Sandstone (generally light-colored sandstones) from the typical red beds (siltstone, mudstone, and shale) of the underlying Kayenta Formation is a transition zone. This transition zone is about 100 ft (30 m) thick and consists of Kayenta-type beds that alternate with Navajo-type sandstones. In order to map the Navajo, it was necessary to pick an arbitrary rock boundary in the transition zone. Fieldwork determined that a light-colored Navajo-type bed 6-18 ft (1.8-5.5 m) thick was traceable throughout the project area; consequently, it was chosen as a key bed for mapping the base of the Navajo.

The middle unit consists of light orange brown (10R6/6 to 10R4/6), mainly fine-grained, firmly to moderately cemented sandstone. The unit has a maximum thickness of about 1,000 ft (300 m).

The upper unit consists of light gray (5R8/2 to 5YR8/1) and very pale orange (10RY8/2), very fine to medium-grained, moderately to loosely cemented sandstone. The unit has a maximum thickness of about 900 ft (270 m).

Grain-size analyses were made of rock samples from 12 selected outcrops and the results of these analyses are in table 1 and in figure 2. The outcrops were selected along several traverses between the top and bottom of the formation; they are considered to represent the typical lithologies of the three subdivisions of the formation.

The median size ranges from 0.10 to 0.29 mm, indicating that the sand grains are very fine to medium, according to the Wentworth grade scale (Krumbein and Pettijohn, 1938, p. 80); the median size of most samples is in the range of fine sand (0.125 to 0.25 mm). More instructive of size, however, is figure 2 showing grain-size distribution curves. Figure 2 graphically shows that sorting of particles is highly developed and by far the largest percentage of particles is in the fine to medium sand range. From the statistical analysis, it is concluded that the Navajo Sandstone is practically homogeneous in the size and sorting of its grains.

Structure

The Navajo Sandstone has primary and secondary structures. Bedding and crossbedding are the main primary structures. The secondary structures include faults, joints, and folds. Bedding is only developed locally in the lower unit. Crossbedding is in all units and because the formation has a significant area of outcrop and is a cliff-former, the crossbedding is a conspicuous and distinguishing natural feature in the project area. Crossbedding has the smallest dimensions in the lower unit and the largest in the middle and upper units.

Table 1.--Statistical characteristics of grain-size analyses

Sample location: See explanation of numbering system for hydrogeologic-data sites.
Unit: L, lower; M, middle; U, upper.

Sample location	Unit	Median size[1] (mm)	Sorting coefficient[2]	Skewness[3]	Kurtosis[4]	Uniformity coefficient[5]
(C-40-13)3bad	L	0.28	1.5	0.85	0.31	2.5
(C-40-14)26dbc	U	.15	1.6	.85	.25	3.1
35aaa	M	.16	1.3	1.0	.24	2.2
35dad	L	.10	1.4	1.1	.24	1.8
(C-41-15)18ddd	U	.15	1.3	.93	.28	2.3
(C-41-16)10dbb	U	.17	1.3	1.0	.24	2.4
(C-41-17)8cca	M	.18	1.4	1.0	.21	2.8
17dbd	L	.23	1.5	1.0	.30	2.1
(C-42-14)24acc	M	.19	1.3	1.0	.20	1.7
34acc	M	.29	1.5	.87	.31	2.6
(C-42-15)6dcc	L	.16	1.3	.95	.27	2.3
20cdb	L	.15	1.5	.93	.26	2.4
Average		.18	1.4	.96	.26	2.4

[1] The fiftieth percentile or the second quartile.

[2] $\sqrt{Q_3/Q_1}$, in which Q_1 and Q_3 are the first and third quartiles, respectively.

[3] $Q_1Q_3/(\text{median})^2$, in which Q_1 and Q_3 are the first and third quartiles, respectively.

[4] $Q_3-Q_1/2(P_{90}-P_{10})$, in which Q_1 and Q_3 are the first and third quartiles, respectively, and P_{10} and P_{90} are the tenth and ninetieth percentiles, respectively.

[5] The sixtieth percentile divided by the tenth percentile.

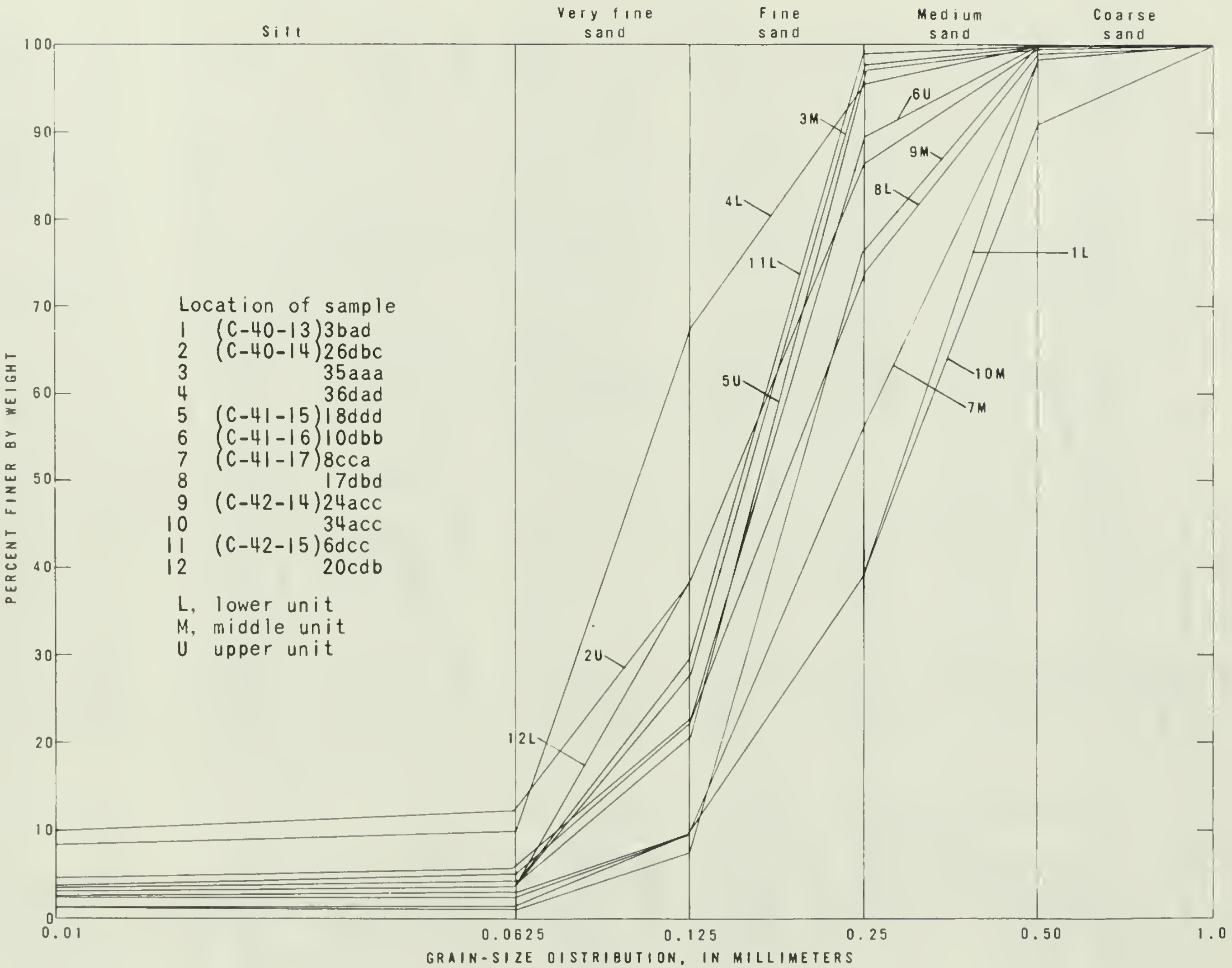


Figure 2.— Grain-size distribution curves.

Several faults (pl. 2) are conspicuous for their length and displacement and these include from east to west (1) the Hurricane fault, a major structure of southwestern Utah, (2) the Leeds fault (named for this report), (3) the Washington fault, (4) the St. George fault (named for this report), (5) the Snow Canyon fault (named for this report),(6) the Ivins fault (named for this report), and (7) the Gunlock fault.

Many short, small-displacement faults traverse the Navajo Sandstone. Many were mapped for this project but there are probably many others that are not obvious because of the difficulties of mapping posed by the almost complete lack of bedding planes. Many of the small mapped faults are grouped at the ends of the large folds such as those in the areas of St. George, Washington, and Leeds. Probably the concentration of stresses at the bends of the folds during deformation resulted in the concentration of the faults. Faulting, inferred to be underthrusting, west of the Gunlock fault has resulted in the Navajo having a width of outcrop perpendicular to the strike that is several times the expected width of an unfaulted stratigraphic section.

Jointing, mainly vertical to nearly vertical, is developed strongly in all outcrops seen by the writer and is probably equally well developed in areas that are covered by unconsolidated deposits and basaltic lava flows. The strong development is seen in aerial photographs of selected areas (figs. 3-7).

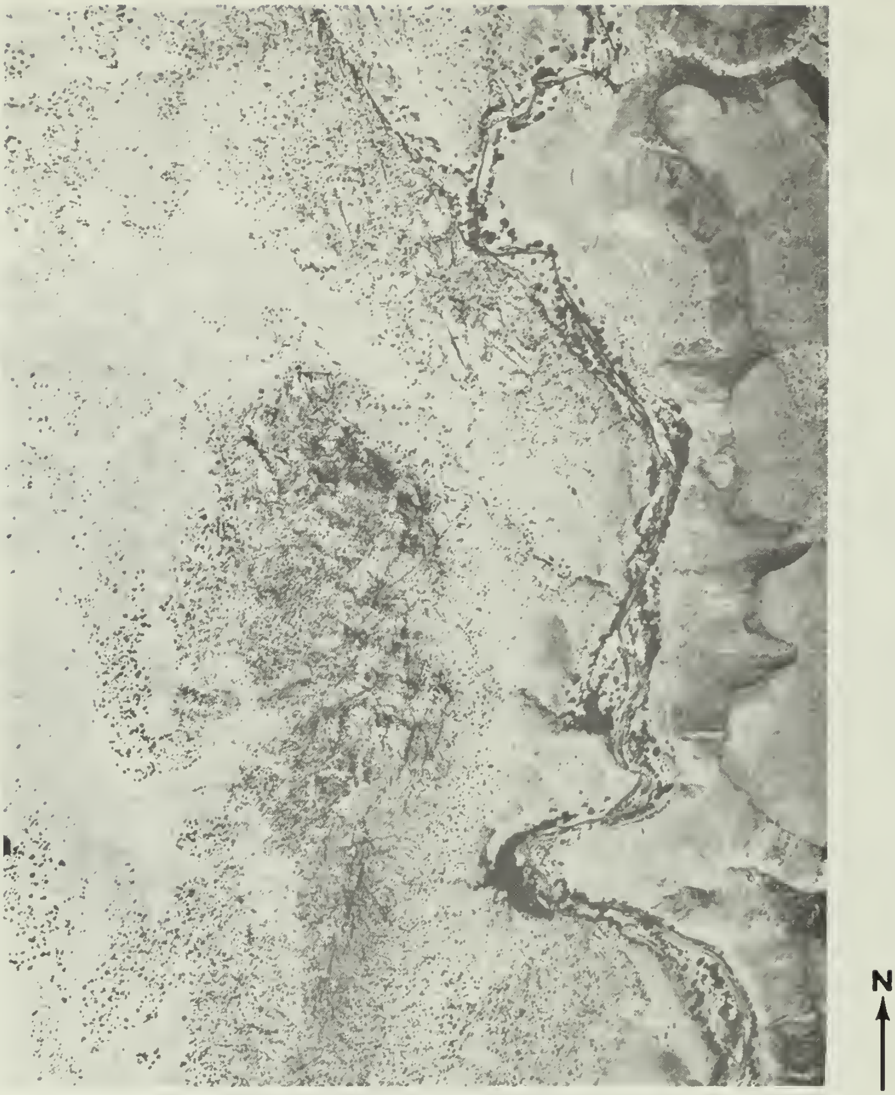
Folds are anticlinal or synclinal and large or small. The major folds that involve the Navajo Sandstone are from east to west (1) the Hurricane Bench syncline, a shallow downwarp; (2) the Virgin anticline, a long, narrow fold of generally steeply dipping strata (the Navajo has been eroded from most of this structure resulting in two large almost completely separated areas of outcrop to the northwest and southeast of the anticlinal axis); (3) the St. George syncline (named for this report), a broad, shallow fold extending from the Virgin anticline to the Gunlock fault; and (4) the Gunlock syncline, a small fold west of the Gunlock fault. Several small folds have been mapped in the eastern and western parts of the project area, and these are probably genetically related to the nearby faulting.

HYDROLOGY

Recharge

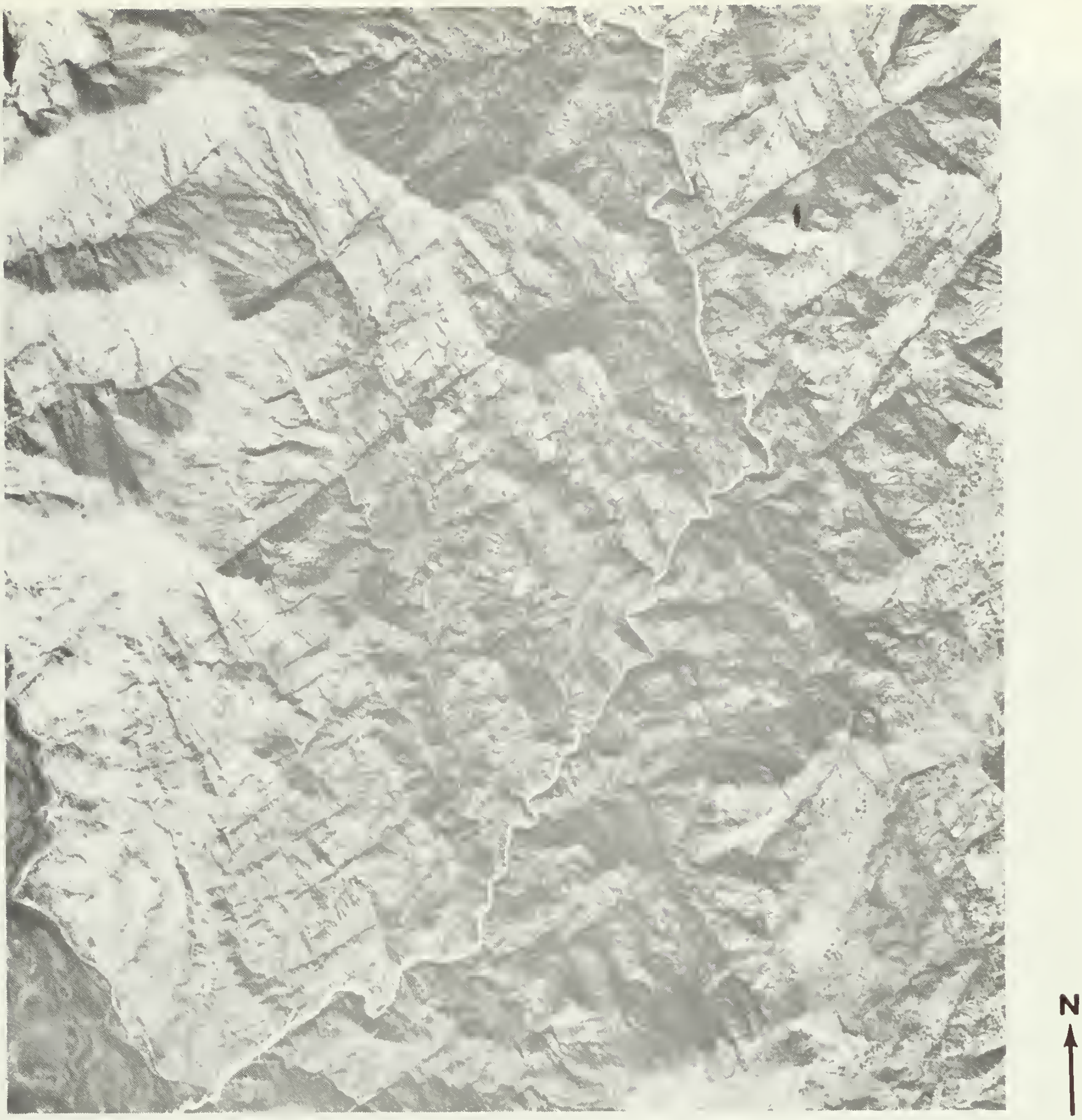
Recharge to the Navajo Sandstone is by (1) infiltration of precipitation directly on the outcrop of the formation, (2) infiltration of streamflow in the outcrop area, (3) infiltration of water from the overlying Carmel Formation, and (4) inflow of ground water from outside the project area. Sufficient data are not available for computing the quantity of recharge from each item of recharge; however, the data prove that there is a significant quantity of recharge from each item.

Recharge occurs by the infiltration of precipitation directly on the Navajo Sandstone outcrop area. However, most of the infiltration occurs where the sandstone is bare and jointed or where only thin sandy deposits cover the jointed rock.



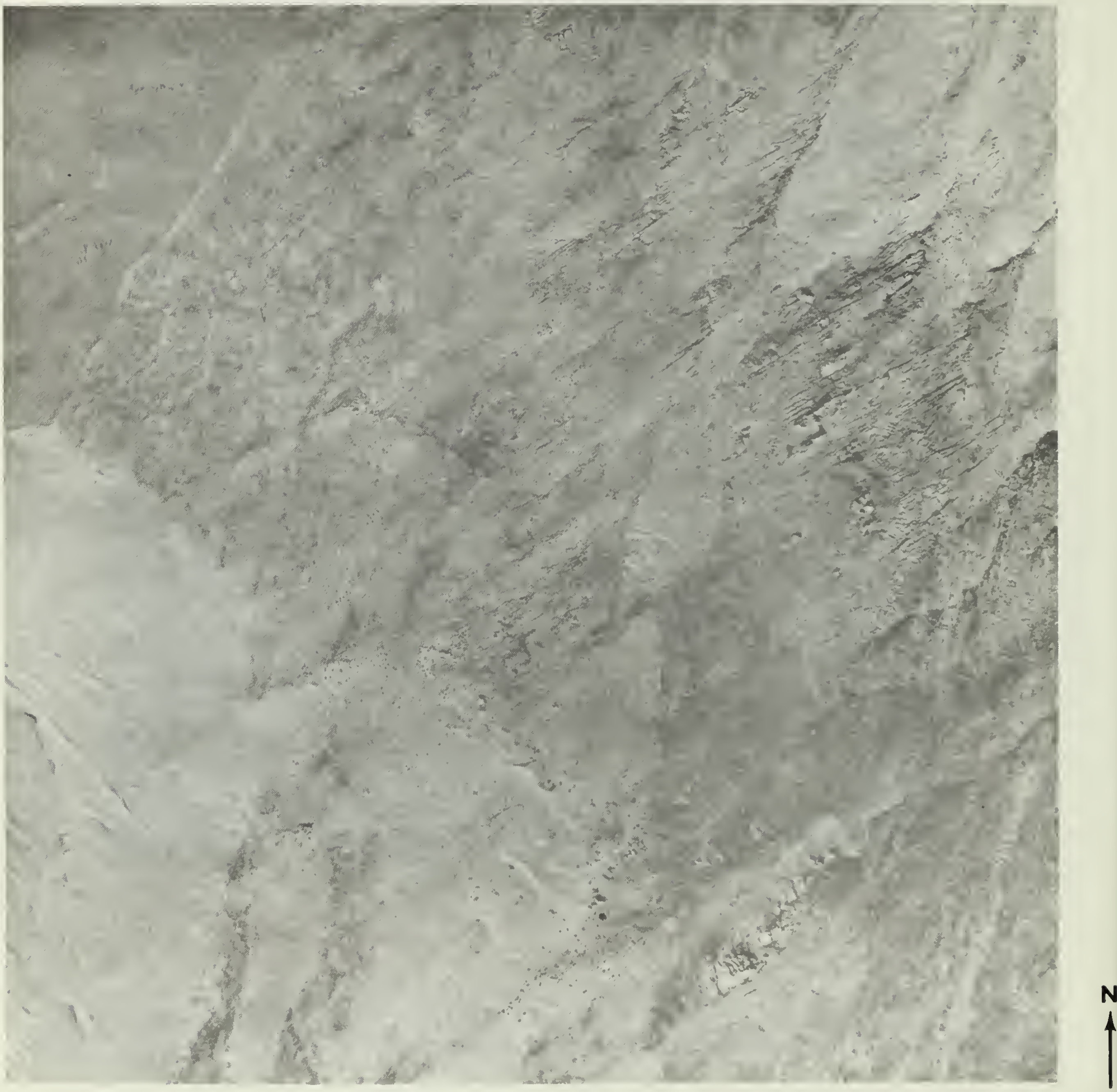
Scale 1 inch equals 0.3 mile approximately

Figure 3.— Aerial photograph of a part of the Gunlock area, secs. 4-9, 16-18, T. 41 S., R. 17 W., showing jointing.
Photograph by Agricultural Stabilization and Conservation Service, 1967.



Scale 1 inch equals 0.3 mile approximately

Figure 4.— Aerial photograph of a part of the upper Mill Creek area, secs. 13-15, 22-27, T. 41 S., R. 15 W., showing jointing. Photograph by Agricultural Stabilization and Conservation Service, 1967.

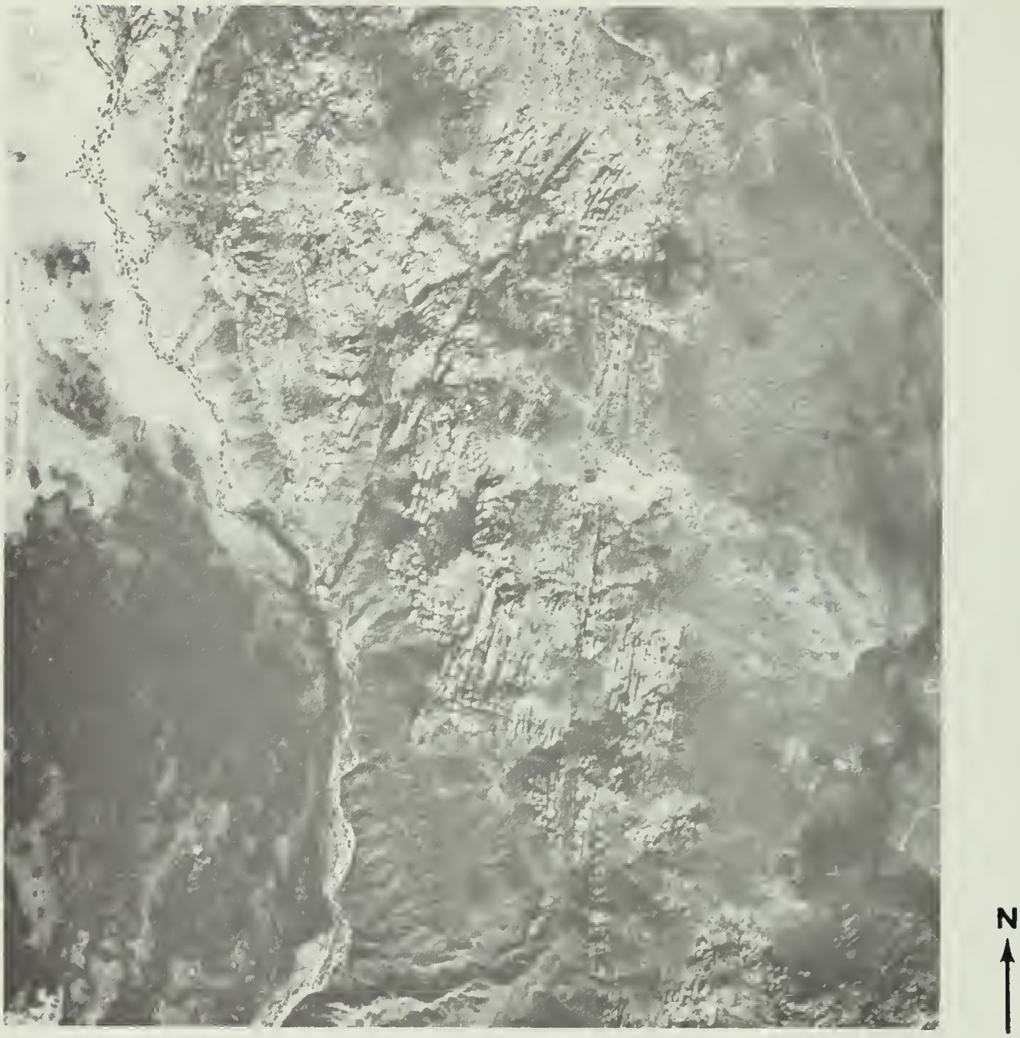


Scale 1 inch equals 0.3 mile approximately

Figure 5.—Aerial photograph of a part of the Sand Mountain area, secs. 25-27, 34, 35, T. 42 S., R. 14 W., showing jointing. Photograph by Agricultural Stabilization and Conservation Service, 1967.

Scale 1 inch equals 0.3 mile approximately

Figure 6.— Aerial photograph of area immediately north of St. George, secs. 17-20, 29, 30, T. 42 S., R. 15 W., and secs. 13, 24, 25, T. 42 S., R. 16 W., showing jointing. Photograph by Agricultural Stabilization and Conservation Service, 1967.



Scale 1 inch equals 0.3 mile approximately

Figure 7.— Aerial photograph of part of Big Sand area, secs. 26-28, 33-35, T. 41 S., R. 16 W., and secs. 2-4, 9-11, T. 42 S., R. 16 W., showing jointing.
Photograph by Agricultural Stabilization and Conservation Service, 1967.

Joints are the main conduits for water moving from the surface to the saturated zone. The widespread occurrence, population density, dimensions, and high permeability of the open joints combine to make a strong argument for this assertion. Some of the direct runoff from precipitation enters unfractured rock where there are pores between the individual grains, but most of the runoff flows into the large voids of the open joints. During rainstorms, the writer has been in canyons formed in highly jointed sandstone and seen runoff flowing into joints and cascading downward inside them. Part of this runoff came out of the joints at the base of the canyon walls and became streamflow and part remained in the sandstone and recharged the aquifer.

Aeolian sand deposits commonly overlie the Navajo Sandstone in the project area. They differ considerably in thickness from place to place, but an estimated maximum thickness is 25 ft (7.6 m). Generally the top of the saturated zone in the Navajo is considerably more than 25 ft (7.6 m) below the land surface so that, in most places, the top of the saturated zone is also below the base of the sand deposits. This means that infiltrating water must generally pass through the sand deposit and through sandstone before reaching the saturated zone. Where the thickness of the overlying sand deposit and of the unsaturated sandstone are significant, the chance of infiltration to the saturated zone is greatly reduced if not nullified.

Water infiltrates the sandstone from streams; this was proved by seepage measurements of two perennial streams and one ephemeral stream. Measurements of the perennial streams--Ash and Leeds Creeks--during periods of low flow in 1974 indicated minimum annual losses of 350 acre-ft (0.43 hm^3) and 160 acre-ft (0.2 hm^3), respectively. During periods of high flow, losses would be larger. The one ephemeral stream measured, whose channel is in fractured bare sandstone, was City Creek north of St. George. The measurements were made when water from a well was in the channel. The test reach was 0.25 mi (0.4 km) long and the loss was 15 percent of the flow entering the reach. Although ephemeral streams carry water for relatively short periods each year, mainly from summer storms, the volume of water lost from them to infiltration may be large. Many such streams cross the Navajo Sandstone where it is highly fractured (figs. 3-7) and has no surficial cover, so that losses could be large.

Recharging water infiltrates the Navajo Sandstone from the overlying Carmel Formation. North of St. George the potentiometric surface (pl. 3) indicates that the movement of ground water in the Navajo is away from the Pine Valley Mountains, a main recharge area. However, in the Pine Valley Mountains the Navajo does not crop out but is overlain by a thick sequence of formations and directly by the Carmel (pl. 1). Therefore, if the formation does not crop out but contains ground water, recharge can occur only by water infiltrating through formations stratigraphically higher than the Navajo.

Ground water flows into the Navajo Sandstone of the project area from the area east of the Hurricane Cliffs. This is inferred from the direction of the gradient of the potentiometric surface (pl. 3) and the

generally poor recharge conditions in the southeastern part of the project area. The potentiometric surface has an overall gradient away from the Hurricane Cliffs south of Hurricane City. Here the saturated Navajo is mainly buried by younger rocks because of graben faulting. Recharge probably does not occur or is no more than negligible in the area just west of the cliffs because the deep saturated zone is overlain by generally more than 300 ft (90 m) of unsaturated materials which are predominantly clay, silt, and very fine sand, that is, materials that tend to reduce significantly or even prohibit water movement.

Ground water flows from the Kayenta Formation into the Navajo Sandstone in the southeastern part of the project area at the southern edge of the Hurricane Bench. This is evidenced by a lack of natural discharge from the nearby Navajo escarpment, by the water level in well (C-43-13)21caa-1, which is in the Kayenta even though the well was spudded in the Navajo, and by water levels in wells on the Hurricane Bench, (downgradient from well (C-43-13)21caa-1), which are in the Navajo. The potentiometric-surface gradient in this part of the area is mainly to the northwest, suggesting that the ultimate source of the water is east of the Hurricane Cliffs.

The complexity of the recharge system and the difficulty of determining the magnitude of each of the items of recharge necessitated the use of a hydrologic-budget equation for estimating the total recharge. The amount of recharge for 1974 was estimated by using the following ground-water budget equation:

$$R = Ds + Dsp + Dl + Dw + De - \Delta S$$

where,

R = total recharge to the Navajo Sandstone in the project area,
Ds = discharge by seepage into streams,
Dsp = discharge by springs,
Dl = discharge by percolation into the Kayenta Formation (unknown),
Dw = discharge by wells,
De = discharge by evapotranspiration, and
ΔS = change of storage (decrease in 1974).

Values for discharge and storage are explained in other sections of this report. Storage in 1974 is assumed to have generally not changed in the project area except for St. George City's Gunlock well field, where declining water-level trends in wells show discharge to exceed recharge. In the Gunlock well field, storage decreased an estimated 1,600 acre-ft (2 hm^3). Substituting the values for each of the items of discharge and change of storage in the ground-water budget equation gives a minimum recharge value (rounded) of 17,000 acre-ft (21 hm^3) as follows:

$$R = 11{,}100\ (14\ hm^3) + 5{,}000\ (6\ hm^3) + Dl\ (\text{unknown})$$
$$+\ 2{,}300\ (2.8\ hm^3) + 500\ (0.6\ hm^3) - 1{,}600\ (2\ hm^3).$$

Movement

Movement of ground water is generally from the Pine Valley Mountains, the Bull Valley Mountains, and the area east of the Hurricane Cliffs toward the Virgin River and its tributaries (pl. 3). Only the part of the Navajo Sandstone from about Toquerville southward to the Arizona line receives water that has originated outside the project area.

A comparison of the general direction of ground-water movement, as shown by potentiometric contour lines, with the attitudes of the large structural features indicates that this direction is independent of the strike or plunge of the structures. That is, the generally smooth-trending contour lines in the vicinity of the structures suggests that the water moves across the structures with no appreciable effect on the direction of movement toward the major surface-drainage lines. However, joints, where open, have a strong influence on the local direction of flow. This is because an open joint having a particular cross-sectional area has a greater permeability than the same cross section of unjointed sandstone having only intergranular openings. The greater permeability of the jointed sandstone means that there is a greater ease of movement of water along joints than through intergranular openings. From figures 3-7 it can be seen that there are two or more joint sets that cross one another in each area. From fieldwork it was seen that some of the individual joints are closed, some are open, and some are sectionalized into open and closed parts. Obviously, the path of a drop of ground water is necessarily a tortuous one as it moves in jointed rocks from recharge areas to the areas of discharge.

Open joints are conspicuous at the land surface and are seen to extend vertically in canyon walls for as much as 200 ft (60 m). However, it cannot be presumed from such observations that the joints are open to considerable depths below the water table because weathering, erosion, and shallow tensional stresses are mainly responsible for the size of the openings at and near the land surface. Probably most joints that are open at the surface gradually close with depth; however, a few major joints are open to significant depths because of deep-seated tensional stresses in the earth's crust. Caliper logging in wells proved that joints are open below the water table (fig. 8). However, most wells do not penetrate more than 60 percent of the formational thickness, so it is not known if joints remain open for the full formational thickness. Assuming that most joints become narrower with increased depth, their importance as conduits of water must decrease with increased depth. With increased depth, therefore, intergranular openings increase in importance as water conduits so that the movement of water is increasingly controlled by these openings and less by open fractures.

Faults theoretically may be permeable and serve as conduits for the movement of water or they may be impermeable and serve as barriers or deflectors. It is also conceivable that a particular fault may be impermeable in one place along its strike and permeable in another place. From geologic fieldwork in the project area, it is inferred that some faults are impermeable at depth.

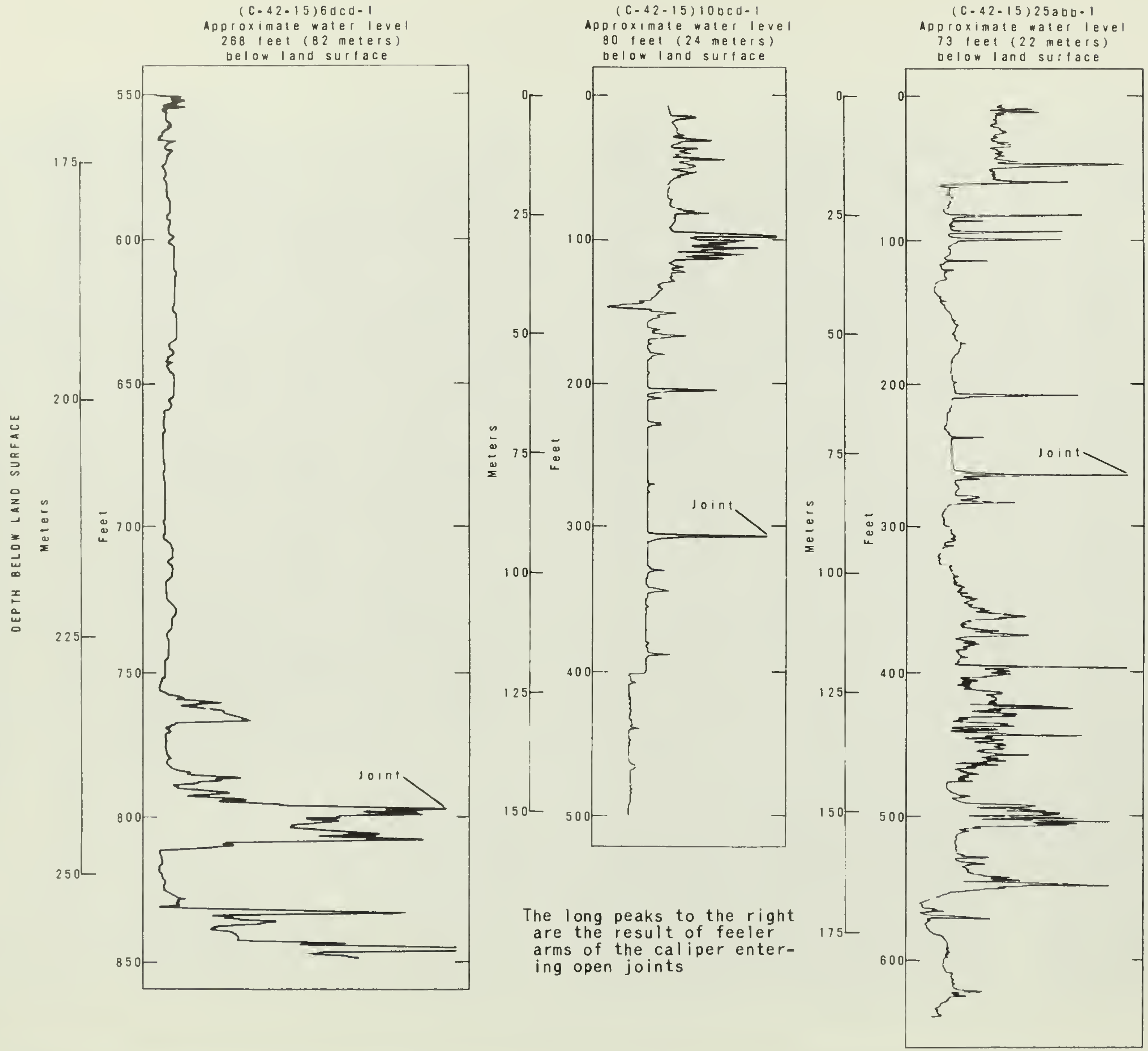


Figure 8.—Caliper logs in wells showing open joints.

Faults in some cases are identifiable in the field by what has been termed for this study, a trellis zone. A trellis zone is narrow and linear and consists of a network of complexly intersecting fractures filled with siliceous cement. These zones are dense, indurated, and more resistant to weathering and erosion than the bordering undisturbed sandstone, resulting in the formation of low hills or ridges.

Trellis zones have been formed by the fracturing of the rock during movement along shear zones, and the filling of the fractures by siliceous cement possibly formed by the in situ mobilization of the silica in the shear zones. Fault zones comprised of dense indurated rock in the saturated zone most probably form impermeable boundaries to the flow of ground water.

Faulting results in the formation of barriers, partial or complete, to the flow of ground water where a formation of low permeability has been juxtaposed against a formation of high permeability. The Gunlock fault illustrates such a case; the Kayenta and older formations of low permeability have been displaced along the fault to a position next to the Navajo Sandstone of higher permeability. Most of the ground water moving in the Navajo toward the fault would be deflected by the low-permeability formations; some water is deflected to the land surface, which is indicated by the seepage inflow to the Santa Clara River.

Thermal water discharging from springs or encountered in wells that are located near or on faults is an indication of some degree of permeability of the fault zone. For example, the St. George fault is inferred to be locally permeable because water near the fault is warmer than expected for the normal temperature gradient of the project area. (See section on temperature.)

Discharge

Discharge of ground water from the Navajo Sandstone is by (1) seepage into streams, (2) springs, (3) percolation into the underlying Kayenta Formation, (4) wells, and (5) evapotranspiration. An accounting of the discharge, in acre-feet, for 1974 is as follows:

Seepage into streams	11,100
Springs	5,000
Percolation into the Kayenta Formation	Unknown
Wells	2,300
Evapotranspiration	500
Minimum total (rounded)	19,000

Seepage into streams

Ground water seeps into the Santa Clara and Virgin Rivers. Seepage into the Santa Clara River in 1974 was 1,100 acre-ft (1.4 hm^3) in the reach that crosses the Navajo Sandstone. Seepage into the Virgin River in 1974 was 10,000 acre-ft (12 hm^3) in the reach that crosses the Navajo. These amounts were determined from seepage runs during periods of low flow.

Springs

The locations of springs are shown on plate 2. Records of these springs and an accounting of spring discharge for 1974 are in table 2. The rounded total discharge for 1974 is 5,000 acre-ft (6 hm^3) and is based on many measurements, especially of the large-discharge springs. Most of the water is used for irrigation. Most springs discharge from the lower unit of the Navajo Sandstone between City Creek (northwest of St. George) and Washington in one of the main areas of natural discharge from the Navajo.

Table 2.--Records of selected springs

Location: See section on numbering system for hydrogeologic-data sites.
Use of water: I, irrigation; P, public supply; R, recreation; S, stock.
Discharge: Totals for 1974 are based on several measurements; e, estimated from records of prior years; U, reported by Ivins city officials, exact date uncertain.
Other data available: C, chemical and temperature data in table 7.

Location	Owner or name	Use of water	Altitude of land surface above mean sea level (ft)	Discharge			Other data available
				Rate (gal/min)	Date of measurement	1974 volume (acre-ft)	
Springs in the Navajo Sandstone							
(C-41-16)34bda-S1	Snow	P	3,060	26	U	40e	C
(C-41-17)17dbd-S1	Pipe	S	3,340	5.5	11-18-74	14.5	C
(C-42-14)15dab-S1	Willow	S	2,880	0	7-2-74	0	
15dbc-S1	Sand Mountain	S	2,875	0	7-2-74	0	
(C-42-15)10a-S1	Mill Creek	P,I	2,940	1,199	11-19-74	1,956	C
14bcb-S1	Myers	I	2,830	11.2	12-13-68	70e	C
15aaa-S1	Warm	I	2,880	449	11-19-74	730	C
15bba-S1	Green	I	2,900	471	11-19-74	635	C
15bbd-S1	Hall	I	2,900	143	11-19-74	102	
16ddd-S2	Huntington	I	2,880	53.9	11-21-74	87	C
19cba-S1	Cox	I	2,980	12.5	11-18-74	20.3	C
20bdb-S1	Trailer Court	R	2,960	6.0	11-19-74	8.9	C
20cad-S1	East St. George	I	2,920	69.1	11-19-74	130	C
(C-42-16)13dcb-S1	West St. George	I	2,960	844	11-19-74	1,223	C
Total (rounded)						5,000	
Springs in formations other than the Navajo Sandstone							
(C-40-13)35acd-S1	Upper Toquerville	S	3,440	-	-	-	
(C-40-17)29dad-S1	Unnamed	I	3,590	-	-	-	
(C-40-18)21dca-S1	Cole	S	4,220	-	-	-	
(C-41-18)2ddd-S1	Pahcoon	S	3,760	-	-	-	
(C-42-14)6cca-S1	Grapevine No. 1	S	3,120	-	-	-	
(C-42-16)10daa-S1	Gray	P	2,960	-	-	-	

Percolation into the Kayenta Formation

Ground water percolates from the Navajo Sandstone into the underlying Kayenta Formation, but the amount of percolation could not be determined from the data available. That this percolation occurs is demonstrated by the fact that within part of the outcrop area of the Navajo the potentiometric surface is below the base of the Navajo. In other words, the Navajo is saturated beneath most of its outcrop area, but locally the potentiometric surface slopes downward beneath the base of the formation. Areas where the potentiometric surface is below the base of the Navajo are shown on plate 3. The location and approximate extent of these areas were determined partly by hydrogeologic fieldwork, partly from wells, and partly by comparing the altitude of the base of the formation with the altitude of the potentiometric surface (pl. 3). The widths of these areas are only roughly approximated and they may be narrower or wider than indicated. The purpose of delineating such areas is to make prospective ground-water users and water-well drillers aware that the thickness of saturated Navajo is not sufficient to complete wells everywhere the formation crops out.

In the outcrop area between the Ivins and Washington faults, the potentiometric-surface gradient indicates that the general flow of ground water is toward the escarpment that forms the southern limit of the outcrop area. Although the Navajo Sandstone is saturated with ground water in this area, natural discharge from the formation is not indicated by springs, seeps, or phreatophytes along most of the escarpment above the base of the Navajo. Therefore, the Kayenta Formation is permeable and ground water is flowing from the Navajo into the Kayenta in this area of outcrop. Ground water is flowing from the Navajo into the Kayenta also in the area from the Washington fault generally northeast to near Pintura, in the area west of the Ivins fault, in the Leeds area, and in the area along the northwest flank of the Hurricane Bench.

In addition, the position of the potentiometric surface at a few wells near the escarpment indicated that the saturated zone was not in the Navajo Sandstone but in the Kayenta Formation. For example, well (C-42-16)1ccd-1 taps the saturated zone about 100 ft (30 m) below the basal contact of the Navajo.

Wells

The locations of selected wells are shown on plate 2. Records of these wells and an accounting of well discharge for 1974 are in table 5. The total discharge from all Navajo Sandstone wells for 1974 was 2,300 acre-ft (2.8 hm^3).

Most wells are used for public supply and irrigation. Most of the well water is pumped for the public supply of St. George City. The depth of the pumped production wells ranges from 54 to 900 ft (16 to 274 m), and the average depth is 275 ft (84 m). However, the well depth is mainly dependent on the depth to the water table, which varies considerably in the project area. Of the developed areas, the depth is least

southwest of Hurricane and near Leeds and is greatest in the Gunlock well field (secs. 7, 8, and 17, T. 41 S., R. 17 W.). The discharge rate ranges from 20 to 2,000 gal/min (1.3 to 126 L/s) and averages about 540 gal/min (34 L/s). Specific capacity determined for a 24-hour period ranges from 9 to 22 (gal/min)/ft [1.9 to 4.6 (L/s)/m] of drawdown and averages about 16 (gal/min)/ft [3.3 (L/s)/m] of drawdown.

Evapotranspiration

Evapotranspiration of ground water by phreatophytes where the water table is at or near the land surface occurs in three localities of the project area, and the average annual amount is estimated to be 500 acre-ft (0.6 hm^3). Phreatophytes are concentrated in the flood plain of the Santa Clara River, along the stream channel below Green Springs, and along the channel of Mill Creek downstream from the Mill Creek Springs. The phreatophytes grow in a mixed relationship, and the most common are cottonwood (*Populus* sp.), saltcedar (*Tamarix gallica*), and the pasture grasses, saltgrass (*Distichlis stricta*) and fescue (*Festuca* sp.). The total area is 140 acres (57 hm^2), and the average annual rate is assumed to be 3.8 acre-ft (0.005 hm^3) per acre (0.4 hm^2).

Hydraulic properties

Porosity

Porosity[1] of the Navajo Sandstone was determined by laboratory analysis (table 3) and by borehole techniques using resistivity and neutron logs (table 4). The laboratory analysis was of rock samples from selected outcrops above the water table. The resistivity and neutron logs were made in wells of different depths that penetrate the saturated zone. Methods for determining porosity from geophysical logs have a distinct advantage over the laboratory method in that they enable the determination of the hydraulic properties of the water-bearing rock under natural conditions.

Laboratory analysis of rock samples indicates that the average effective porosity of 17 percent is about 53 percent of the average total porosity of 32 percent.

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[1]The porosity of a rock or soil is its property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume. It may be expressed as a decimal fraction or as a percentage. Effective porosity refers to the amount of interconnected pore space available for fluid transmission. It is expressed as a percentage of the total volume occupied by the interconnecting interstices.

Table 3.--Porosity of the Navajo Sandstone determined from rock samples from selected outcrops

Location of sample	Effective porosity (percent)	Location of sample	Effective porosity (percent)
(C-40-13)3bad	11.0	(C-41-17)8cca	14.6
(C-40-12)26dbc	13.4	17dbd	12.0
35aaa	25.1	(C-42-14)24acc	10.4
36	25.2	34acc	16.6
(C-41-15)18ddd	19.7	(C-42-15)6dcc	17.6
(C-41-16)10dbd	19.5	20cdb	20.7
		Average (rounded)	17

Table 4.--Porosity of the Navajo Sandstone determined from resistivity and neutron logs of wells

Total porosity: Value is an average of both types of logs.
Type of log used: N, neutron; R, resistivity.

Well	Total porosity (percent)	Type of log used
(C-41-13)6aac-1	34	N, R
31acd-1	40	N
(C-41-16)16cdb-1	46	N, R
(C-41-17)7ada-1	30	N
(C-42-13)7bba-1	29	N, R
18bcb-1	40	N, R
18bcb-2	37	N, R
(C-42-14)25abb-1	20	N, R
(C-42-15)6dcc-1	34	N, R
6dcd-1	40	N, R
10bcd-1	18	N, R
15abb-1	21	N, R
(C-42-16)1ccd-1	25	N, R
Average	32	

Hydraulic conductivity, transmissivity, and storage coefficient

Laboratory analysis of rock samples from outcrops of Navajo Sandstone by the U.S. Geological Survey indicates an average horizontal hydraulic conductivity (*K*)[1] of 2.1 ft/d (0.64 m/d). Tabulated below are the laboratory values:

Location of sample	Unit	*K* (horizontal hydraulic conductivity at 60°F) (ft/d)
(C-40-14)26dbc	Upper	0.49
35aaa	Middle	5.0
36dad	Lower	2.5
(C-41-15)18ddd	Upper	2.0
(C-41-16)10dbd	Upper	1.8
(C-41-17)8cca	Middle	.36
(C-42-15)6dcc	Middle	3.4
20cdb	Lower	.98
Average (rounded)		2.1

This average value of *K* is probably most reliable for parts of the aquifer where fracturing plays a minor role in the transmission of water. This is because the laboratory analyses do not include the effects of open fractures or other secondary openings which would increase the formational *K*. The sample *K*, therefore, may be only a minimum value for the formation where it was taken. A more realistic formational *K* can best be determined using aquifer tests. Aquifer tests conducted for this project are described below.

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[1]The hydraulic conductivity (*K*) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for *K* are cubic feet per day per square foot [$(ft^3/d)/ft^2$], which reduces to ft/d. The term hydraulic conductivity replaces the term field coefficient of permeability, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per square foot. To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, divide by 7.48; to convert from hydraulic conductivity to coefficient of permeability, multiply by 7.48.

Where aquifer-test data are unavailable, transmissivity (*T*)[1] for the Navajo Sandstone in a particular locality can be roughly estimated by multiplying the average sample *K* by the saturated thickness; the saturated thickness can be determined for some localities by the use of plates 2 and 3. For example, assume that at a certain point within the area of outcrop of the Navajo the altitude of the land surface (pl. 3) is 3,200 ft (975 m), the altitude of the potentiometric surface (pl. 3) is 3,000 ft (914 m), and the formational thickness (pl. 2) is 750 ft (230 m). Then, the saturated thickness is 550 ft (168 m), which is found by subtracting the difference between the land-surface altitude and the potentiometric-surface altitude from the formational thickness. For localities where there is no potentiometric-surface data, water-level altitudes can be extrapolated fairly accurately from another locality within reasonable distance. If the difference in altitude between the land surface and the potentiometric surface equals or exceeds the thickness of the formation, there is no saturated Navajo at that point.

Transmissivity (*T*) and storage coefficients (*S*)[2] were determined from aquifer-test data in three areas; the aquifer tests are discussed in the next section. The values for *T* and *S* are listed below:

Test area	*T* (ft^2/d)	*K* (ft/d)	*S* (dimensionless)
Gunlock	5,300	6.1	0.04
City Creek-Mill Creek			
Test No. 1	5,000	5.0	-
Test No. 2	2,400	3.4	-
Test No. 3	5,000	5.0	.04
Hurricane Bench	2,700	5.2	-
Average (rounded)	4,000	5	.04

The values are useful for the determination of relatively short-term effects of pumping in well fields and for the design of new well fields.

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[1]Transmissivity (*T*) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for *T* are cubic feet per day per foot [$(ft^3/d)/ft$], which reduces to ft^2/d. The term transmissivity replaces the term coefficient of transmissibility, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, divide by 7.48; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48.

[2]The storage coefficient (*S*) of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in head. Under confined conditions, *S* is typically small, generally between 0.001 and 0.00001. Under unconfined conditions, *S* is much larger, typically from 0.05 to 0.30.

Aquifer tests

Purpose and procedure for testing

The hydraulic constants of an aquifer can be determined by several methods, one of the most important being the aquifer or pumping-test method. This method utilizes a well which is pumped and one or more wells that are used to observe the change of water levels that results from the pumping. The chief advantage of this method is in the relatively large volume of water-bearing material that can be tested.

Following is an outline of the testing procedures used. The aquifer tests were evaluated using the type curves and assumptions stated by Prickett (1965). For several days prior to the aquifer tests, water levels were measured in the pumped and observation wells, and the discharge was measured at selected springs to determine the trend of changes in ground-water storage in the areas to be tested. During the pumping period, the discharge was maintained at a nearly constant rate, while water levels were measured periodically using the wetted-tape method or by using automatic water-stage recorders. Water levels were measured from a stable point (called the measuring point) on the well casing or on a special tubing for water levels attached to the inside of the casing. Discharge was measured periodically using either a Parshall flume, in-line flow meter, Hoff meter, or Cox meter. The temperature and conductivity of the water were also collected several times during the test. After the pump was turned off, water levels and spring discharges were measured for a period of time comparable in length to the pumping period.

Description of tests

Gunlock area.--The location of the wells used in the test and other pertinent information are shown in figure 9 and in table 6.

The pump of well (C-41-17)8cda-1 was turned on January 22, 1974, and turned off February 6, 1974, for a total pumping time of 15 days. The average rate of pumping was 1,960 gal/min (124 L/s), but the instantaneous rate dropped from 2,600 gal/min (164 L/s) 10 minutes after the test was started to 1,875 gal/min (118 L/s) just prior to turning off the pump. The drawdown was 121.5 ft (37.0 m) at the end of 15 days. The 24-hour specific capacity was 22 (gal/min)/ft [4.6 (L/s)/m] of drawdown.

Pumping from well (C-41-17)8cda-1 caused observed drawdowns in only two of the four observation wells--(C-41-17)8cac-1 and (C-41-17)17bdb-1. The maximum observed drawdown in well (C-41-17)8cac-1 was 8.45 ft (2.58 m), and the drawdown in well (C-41-17)17bdb-1 was 1.37 ft (0.42 m). There was no observed drawdown in wells (C-41-17)7ada-1 and (C-41-17)7ddb-1.

The reason for the two observation wells not being affected is because pumping did not continue long enough for detectable effects to reach them. At these two wells, computed drawdowns were only 0.33 and

0.24 ft (0.10 and 0.07 m) at the end of the 15 days, using T = 5,300 and S = 0.04. It is difficult to segregate such relatively small drawdown effects from other miscellaneous water-level fluctuations in the wells. A longer pumping period (from one or more wells), however, would eventually produce detectable interference effects in the farthest observation well in the area.

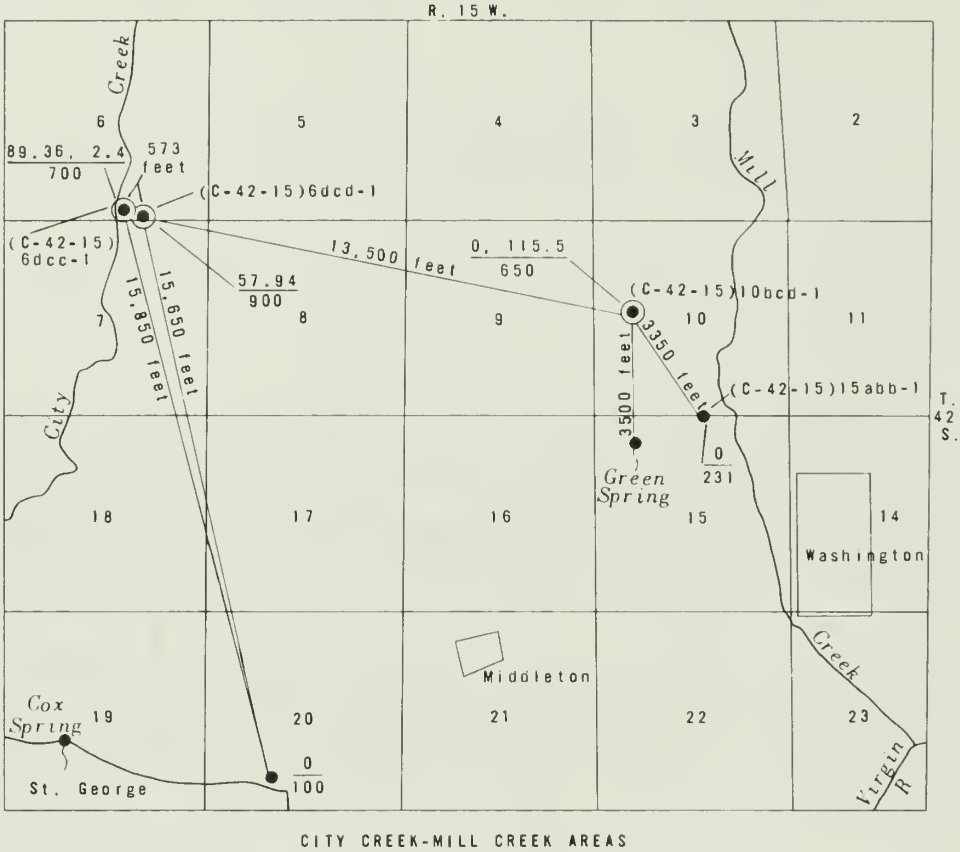
City Creek-Mill Creek areas.--The location of the wells used in three aquifer tests and other pertinent information are shown in figure 9 and in table 6. The first test in time sequence involved wells (C-42-15)6dcc-1, (C-42-15)10bcd-1, and (C-42-15)20cdb-1 and Cox Spring, (C-42-15)19cba-S1; the second involved wells (C-42-15)10bcd-1 and (C-42-15)15abb-1 and Green Spring, (C-42-15)15bba-S1; and the third involved wells (C-42-15)6dcc-1, (C-42-15)6dcd-1, (C-42-15)10bcd-1, and (C-42-15)20cdb-1.

In the first test, well (C-42-15)6dcc-1 was turned on July 25, 1973, and pumped almost continuously (except for short stops for maintenance that averaged about 15 minutes daily) until August 22, 1973, for a total time of practically 28 days. The average rate of pumping measured by Parshall flume was 1,330 gal/min (84 L/s). The drawdown was 89.36 ft (27.24 m). The 24-hour specific capacity was 21 (gal/min)/ft [4.3 (L/s)/m] of drawdown.

Pumping from well (C-42-15)6dcc-1 did not cause drawdowns in the observation wells or reduce the observed discharge from Cox Spring. There is either a lack of hydraulic connection between the pumped well and the observation points or the aquifer is unconfined. A lack of hydraulic connection could be caused by an impermeable fault zone especially to the east of the pumped well where a major fault is inferred from geologic mapping. Assuming an unconfined condition in the aquifer, a storage coefficient of 0.04, a transmissivity of 5,000 ft^2/d (464 m^2/d), then it would take more than 30 days for any drawdown to occur at the nearest observation well.

In the second test, well (C-42-15)10bcd-1 was turned on May 18, 1974, and pumped continuously until May 28, 1974, for a total time of 10 days. The average rate of pumping was about 1,000 gal/min (63 L/s). The total drawdown was 115.5 ft (35.2 m). The 24-hour specific capacity was 10 (gal/min)/ft [2 (L/s)/m] of drawdown.

Pumping from well (C-42-15)10bcd-1 did not cause measureable drawdowns in the observation well or a decrease in discharge from Green Spring. The lack of interference effects is probably the result of an unconfined condition in the aquifer. This conclusion is based on the following: (1) the aquifer (Navajo Sandstone) is exposed at the land surface and neither drilling nor field study indicated a hard impermeable zone above the saturated zone which is less than 80 ft (24 m) below the land surface; and (2) if the aquifer is confined, a drawdown of 0.1 ft (0.03 m) would have occurred in observation well (C-42-15)15abb-1 in less than 12 hours after pumping started, assuming an artesian storage coefficient of 1×10^{-3} and a transmissivity of 2,400 ft/d (730 m/d).



EXPLANATION

$\frac{0}{231}$ ● Observation well

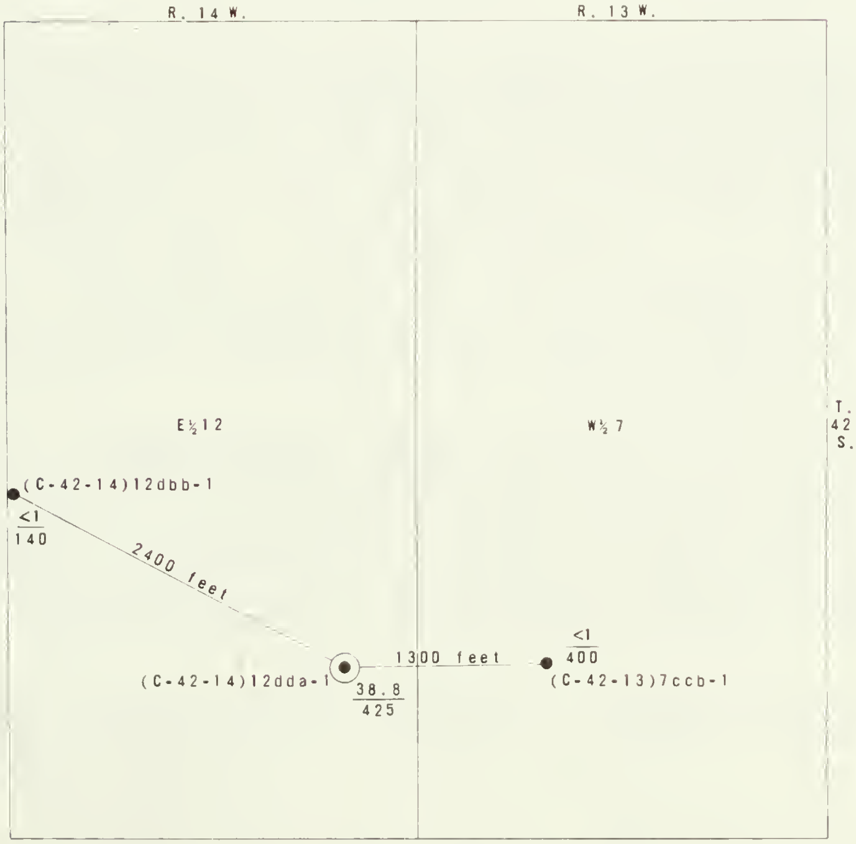
◉ Pumped well

$\frac{0,\ 115.5}{650}$ *Upper number is drawdown, in feet; if more than one number, first is for test in which well was pumped, second is for test in which well was not pumped. Lower number is depth of well, in feet*

Spring

Figure 9.—Map showing location of wells and springs, distances from pumped wells to observation wells and springs, total drawdown, and depths of wells for selected aquifer tests in the Navajo Sandstone.

GUNLOCK AREA



HURRICANE BENCH AREA

Figure 9.— Continued.

The absence of interference effects after 10 days of pumping indicates a storage coefficient that is probably on the order of 0.04 or in the range of values for other test sites in the project area.

In the third test, well (C-42-15)6dcd-1 was turned on January 29, 1975, and pumped continuously until February 2, 1975, for a total time of about 4 days. The average rate of pumping was about 640 gal/min (40 L/s). The total drawdown was 57.94 ft (17.66 m). The 24-hour specific capacity was 20 (gal/min)/ft [4.1 (L/s)/m] of drawdown. The specific capacity for the first step was more than for the second step when it was 18.8 (gal/min)/ft [3.9 (L/s)/m] of drawdown. During the second step, the average pumping rate was 1,100 gal/min (335 L/s) compared to the average of 470 gal/min (143 L/s) for the first step. The increase in pumping rate by more than twice caused an increase in the friction head loss in the aquifer and well that resulted in the pumping water level in the well being lowered considerably. The lower water levels in the wells resulted in a diminished amount of openings through which water could enter by 5.5 percent. The specific capacity is diminished a like amount or 1.2 (gal/min)/ft [0.2 (L/s)/m], thus accounting for most of the diminished specific capacity during the second step.

Pumping of well (C-42-15)6dcd-1 caused drawdown in observation well (C-42-15)6dcc-1 but at no other point of observation. The drawdown was 2.4 ft (0.73 m).

Leeds area.--The location of the two wells used in the test and other pertinent information are shown on plate 2 and in table 6. The pump of well (C-41-13)5bbc-1 was turned on October 7, 1974, and pumped continuously until October 11, 1974, for a total pumping time of practically 4 days. The average pumping rate was about 600 gal/min (38 L/s). The water level prior to pumping was 79.22 ft (24.15 m) below land surface. Water levels could not be measured accurately during pumping because of water leakage from the pump column; water levels during recovery could be measured accurately. The estimated drawdown is 40 ft (12 m). The estimated 24-hour specific capacity is 14 (gal/min)/ft [2.9 (L/s)/m] of drawdown.

Pumping from well (C-41-13)5bbc-1 caused drawdown in the single observation well (C-41-13)6aac-1 about 1,650 ft (500 m) to the west. The drawdown was 1.63 ft (0.49 m). Interpretation of the test data indicated a transmissivity of 3,500 ft^2/d (325 m^2/d) and a storage coefficient of 0.05. However, these values are not representative of the Navajo Sandstone alone but represent also an unknown saturated thickness of the underlying Kayenta Formation.

Hurricane Bench.--The location of the wells used in the test and other pertinent information are shown in figure 9 and in table 6. The pump of well (C-42-14)12dda-1 was turned on October 23, 1974, and pumped continuously until October 30, 1974, for a total pumping time of about 7 days. The average pumping rate was about 400 gal/min (25 L/s). The total drawdown was 38.8 ft (11.8 m). The 24-hour specific capacity for the test was 12 (gal/min)/ft [2.5 (L/s)/m] of drawdown.

Pumping of well (C-42-14)12dda-1 caused drawdowns in observation wells (C-42-13)7ccb-1 and (C-42-14)12dbb-1 of less than 1 ft (0.33 m). However, interpretation of the water-level data indicated that infiltration of the water discharged from the pumped well was reaching the saturated zone and causing a significant decrease in the rate of drawdown in the wells. As a result, data from the observation wells could not be used satisfactorily in determining aquifer coefficients.

Storage

Changes

Changes in the amount of ground water in storage are a direct function of the changing relation between recharge and discharge. When recharge exceeds discharge, water levels in wells rise as the amount of water in storage increases and spring discharge increases. Conversely, when discharge exceeds recharge, water levels decline and spring discharge decreases. In the Navajo Sandstone of the project area, changes in storage are controlled mainly by precipitation and well discharge.

Figure 10 shows the relation of water levels in a well and discharges from two springs to changes in precipitation, and table 8 shows periodic water-level measurements in 20 observation wells.

A significant long-term change in storage in the Navajo Sandstone north of the St. George-Washington area has not occurred during the period of record as inferred from spring discharge (fig. 10). This inference is valid because the springs are part of a main discharge area of the formation. From 1965 to 1974, when precipitation was above average 7 out of 10 years, the maximum discharges were slightly larger at the end of this period than at the beginning, a result of the increased precipitation, which produced above-average recharge.

Water levels in most observation wells (figs. 10 and 11) show no significant changes in storage during the periods of record. In most of the localities represented by these wells, levels in 1974 were slightly higher at the end of the year than at the beginning, indicating that the above-average precipitation increased the amount of water in storage and replenished the water pumped. However, the water level in observation well (C-41-17)7ada-1 in St. George City's Gunlock well field declined almost steadily from the beginning of record in 1966 (fig. 10). This general decline is in opposition to the general rise of the cumulative-departure curve or precipitation at St. George; in the 10-year period 1966-75, seven of the years had above-average precipitation. Therefore, the water-level decline indicates a local decrease of water in storage due to pumping from the Gunlock well field. The largest water-level decline began in 1970 when the pumping demand increased significantly as shown on the next page:

Calendar year	Acre-feet
1968 (first year of pumping)	163
1969	202
1970	1,295
1971	734
1972	1,521
1973	420
1974	1,763

In addition to the observation well, the four pumped wells in the Gunlock well field have static water levels that are about 7 to 22 ft (2.1 to 6.7 m) lower in 1974 than when pumping began in 1968. The small

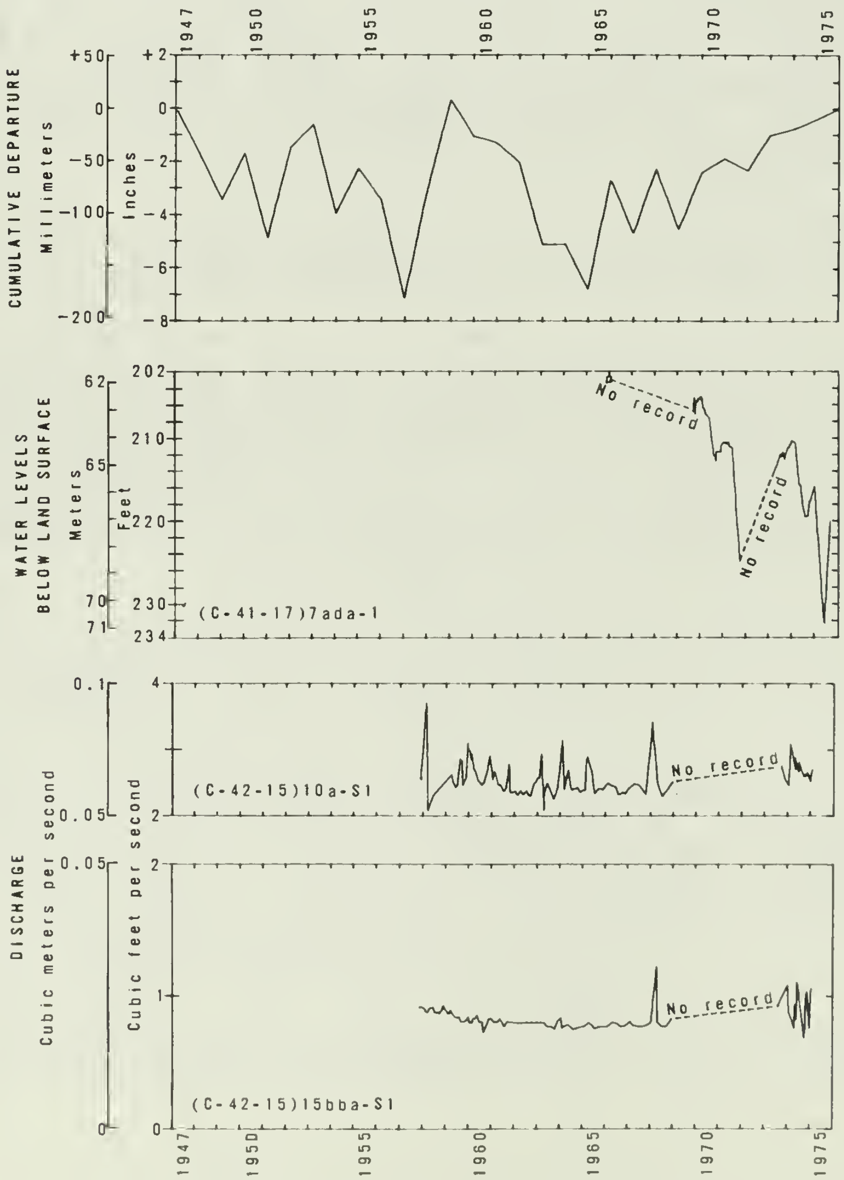


Figure 10.— Relation of water levels in a well and discharge from two springs to cumulative departure from the 1947-75 average annual precipitation at St. George.

amount of pumpage in 1973 allowed a partial recovery of water level at the Gunlock well field, but when heavy pumping was initiated again in 1974, water levels again began to decline.

When water is pumped from a well in the Gunlock well field, some ground water that would otherwise discharge naturally as springs and seeps into the Santa Clara River is diverted to that well. Increasing the pumping rate or the length of the pumping period increases proportionately the dimensions of the cone of depression in the potentiometric surface around the well and the natural discharge decreases. When demand at the well or well field exceeds the supply from diverted natural discharge and recharge, water is mainly from storage in the aquifer; streamflow may supply part of the demand if the gradient of the potentiometric surface is toward the well.

Based on water levels in well (C-41-17)17ada-1 (fig. 10), which indicates that a significant downward trend began in 1970, it is inferred that most of the well discharge from 1970 was supplied by ground water in storage. Also, it is estimated that all pumpage annually exceeding 200 acre-ft (0.25 hm^3), that is, the rounded average of pre-1970 pumpage, is water from storage. In 1974, therefore, about 1,600 acre-ft (2 hm^3) of the total pumpage of 1,763 acre-ft (2.2 hm^3) was derived from storage.

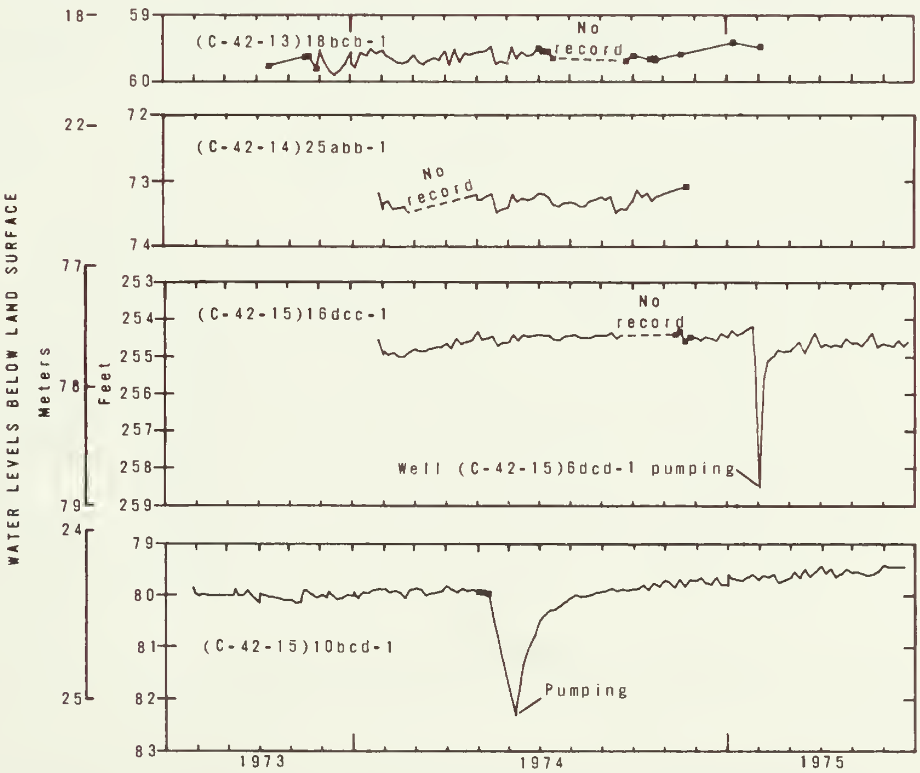


Figure 11.— Water levels in selected observation wells.

Amount

The amount of ground water in storage is estimated to be 12 million acre-ft (1,480 hm^3). (See table 5.) The amount represents the gravity water that is in interconnected pores and that is in transit from recharge to discharge areas. However, only a small percentage of this amount can be obtained by the use of wells (table 5). The maximum amount of ground water in storage available to wells is estimated to be 2.8 million acre-ft (3,450 hm^3). (See table 5.)

The storage capacity for the part of the Navajo Sandstone that underlies younger rocks in about 450 mi^2 (1,200 km^2) of the basin was not calculated but would be a significant amount. The amount was not calculated because there are no data. There is the distinct possibility that the permeability and porosity are much lower than in the area of outcrop because of a thick overburden and abundant evidence of igneous intrusive activity (fig. 3). Both the thick overburden which would promote compaction and cementation, and the igneous rocks by the infilling of voids and contact metamorphism, would be expected to decrease the magnitude of aquifer characteristics like permeability and porosity.

Hydrologic effects of discharging wells

The discharge of ground water from a well results in a cone of depression in the water table or potentiometric surface around the well. Such a cone continues to enlarge in area and deepen until a balance is reached between the amounts of water demanded at the well and supplied to the well. Changes in the demand at the well cause the cone of depression to change in size. Assuming a constant discharge rate and uniform hydraulic conditions, long periods of pumping cause relatively extensive and deep cones, whereas short periods of pumping result in cones

Table 5.--Ground-water storage in the Navajo Sandstone of the central Virgin River basin

Area[1]	Number of acres[2] (1)	Estimated average saturated thickness (ft) (2)	Average effective porosity[3] (3)	Ground water in storage[4] (acre-ft, rounded) (4)	Average storage coefficients[5] (5)	Maximum ground water available to wells by lowering potentiometric surface to base of aquifer[6] (acre-ft, rounded) (6)	Maximum ground water withdrawable under optimum conditions of well spacing[7] (acre-ft, rounded) (7)
Gunlock	9,300	620	0.17	980,000	0.04	230,000	180,000
St. George	49,600	700	.17	5,900,000	.04	1,400,000	1,100,000
Leeds	30,000	360	.17	1,800,000	.04	430,000	340,000
Hurricane Bench	40,500	430	.17	3,000,000	.04	700,000	560,000
Totals (rounded)	129,400	-	-	12,000,000	-	2,800,000	2,200,000

[1]Gunlock area is west of the Gunlock fault; St. George area is between the Gunlock and Washington faults; Leeds area is between the Washington and Leeds faults; Hurricane Bench area is generally south of Leeds fault.
[2]Includes the saturated part of the Navajo Sandstone in the area of outcrop and in the areas overlain by lava flows and unconsolidated rocks (pl. 3).
[3]See section of report on porosity.
[4]Estimated by multiplying the average effective porosity (17 percent) by the volume of saturated rock which is the product of the area of the formation (column 1) and the average saturated thickness (column 2).
[5]Based on aquifer testing and assumed to be constant for the project area.
[6]Estimated by multiplying column 5 by columns 1 and 2.
[7]Assumed to be 80 percent of column 6.

of relatively small extent and depth. The hydrologic effects of wells discharging from the Navajo Sandstone in the central Virgin River basin include interference between wells and reduction of streamflow.

Interference between wells

Interference occurs between wells when the cone of depression of one discharging well overlaps the cone of another. Such overlaps increase the drawdowns and thus reduce the rates of discharge in the affected wells. The magnitude of these effects is dependent upon the hydraulic properties of the aquifers, the rates of discharge, the distance between wells, and the length of the period of discharge.

Aquifer tests showed that interference will occur in significant amounts in several localities. The wells in which drawdown was induced by a pumping well and the amounts of drawdown are shown in figure 9.

Interference to varying degrees can be assumed for any present or potential well site in the Navajo Sandstone, especially where the ground water is under confined conditions or where wells are closely spaced. The confined condition in the formation is locally known or inferred from the quick response of water levels in observation wells to nearby pumping wells, from the sympathetic response of water levels to barometric changes, and from the presence of open fractures in the saturated zone where the fractures confine water as if it were in pipes. The analytical results of data from pumping tests show that the water is partly confined locally. The effects of confinement diminish rapidly with pumping time and distance from the pumped well.

Reduction of streamflow

Discharge from a well can affect streamflow where there is hydraulic connection between a stream and the aquifer from which a discharging well is withdrawing water. Where an aquifer is hydraulically connected to a stream channel, wells discharging water from the aquifer may divert streamflow or water that would otherwise discharge into the stream channel as springs or seeps.

Hydraulic connection between streams and the aquifer system of the Navajo Sandstone is known for the Virgin and Santa Clara Rivers. Seepage runs made in these perennial streams indicated contributions of ground-water flow to the streamflow. Therefore, wells discharging from the Navajo would divert ground water that under natural conditions contributes to the flow of these streams.

Chemical quality and temperature

General relations

Important factors affecting the chemical quality of ground water are the availability of soluble substances in the aquifers through which the water moves and the length of time the water is in contact with

these soluble substances. The Navajo Sandstone is mineralogically a relatively pure lithologic unit composed mostly of silica and other low-solubility substances. The water that flows through such a lithologic medium would expectedly dissolve relatively small amounts of minerals even if the water was in contact with them for a long time. Chemical analysis of the water in storage (table 7) indicates that the concentration of dissolved solids and of the principal ions, in milligrams per liter, ranges widely as shown below.

	Range	Average
Dissolved solids	103-1,360	684
Bicarbonate	81-309	198
Sulfate	8.1-610	222
Chloride	5.0-380	106
Silica	3.5-36	19
Calcium	17-140	76
Magnesium	6.4-58	22
Sodium	0.3-290	98

The wide range in concentration of these constituents is mainly a result of waters passing through different chemical environments within the saturated zone although the transit time from recharge to discharge areas is also operative. Water percolating in the middle and upper units of the Navajo Sandstone generally has a relatively small amount of dissolved solids, for example, in the Gunlock, Snow Canyon, Hurricane Bench, and Leeds areas. However, water that percolates in the lower unit and along or near some faults has the largest amount of dissolved minerals; this is seen in and north of the St. George-Washington area (pl. 3) where most springs discharge from the lower unit and faults are numerous.

The concentration of dissolved substances in water is related to the specific conductance, which is a measure of the ability of the water to conduct an electrical current. The relations of the concentrations of dissolved solids and the ions of sulfate and chloride to specific conductance are shown in figures 12, 13, and 14, respectively; these figures can be used to estimate the concentrations if the specific conductance is known.

The plots of data in figures 12, 13, and 14 indicate that there is no direct relation between the depth below land surface of the saturated zone and either the concentration of dissolved solids or the concentrations of sulfate and chloride ions. The differences in chemical character of the ground water are therefore probably a function of geographic location because the Navajo Sandstone would be expected to have differences of composition from place to place.

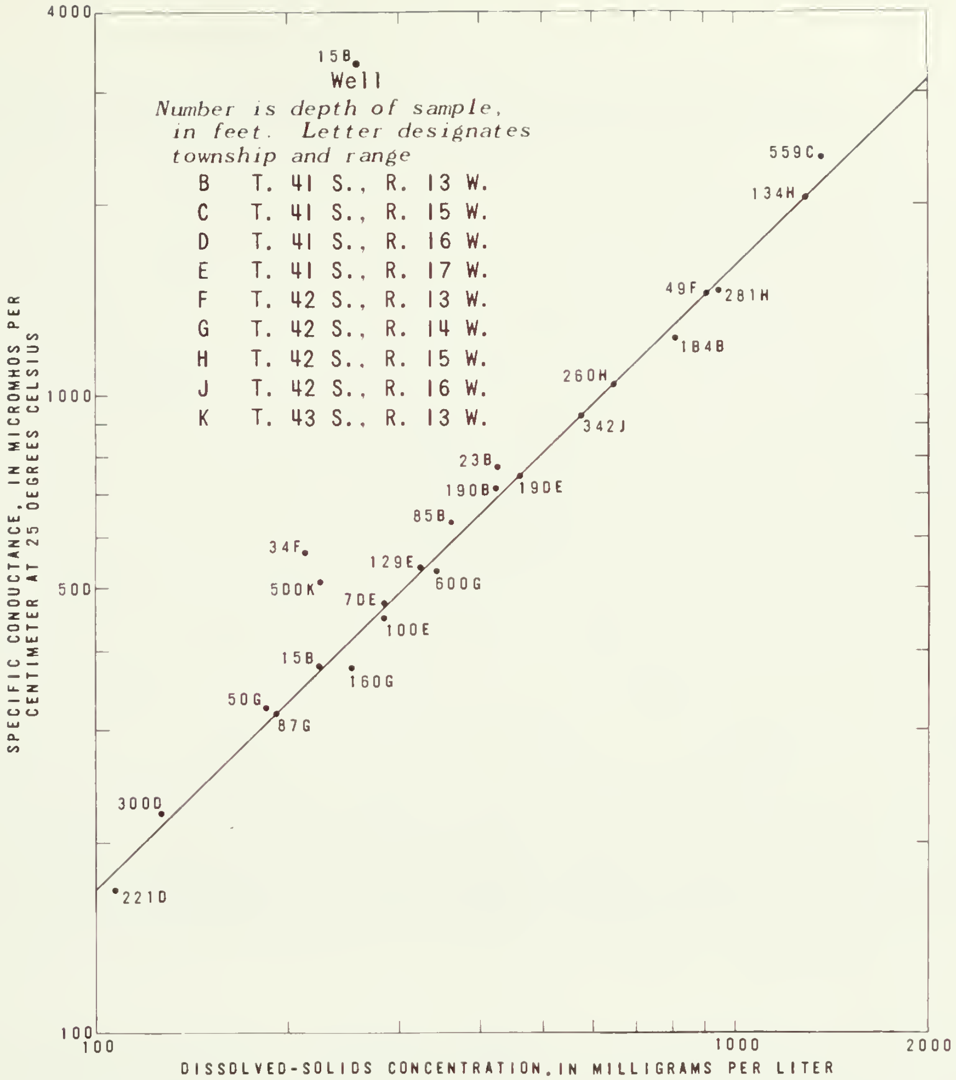


Figure 12.—Relation of dissolved-solids concentration to specific conductance of ground water from the Navajo Sandstone.

Relation to use

Public supply

The U.S. Public Health Service (1962) has recommended quality standards for public drinking water and water-supply systems. A partial list of these standards is as follows:

Constituent	Recommended maximum limit (mg/L)
Dissolved solids	500
Sulfate	250
Chloride	250

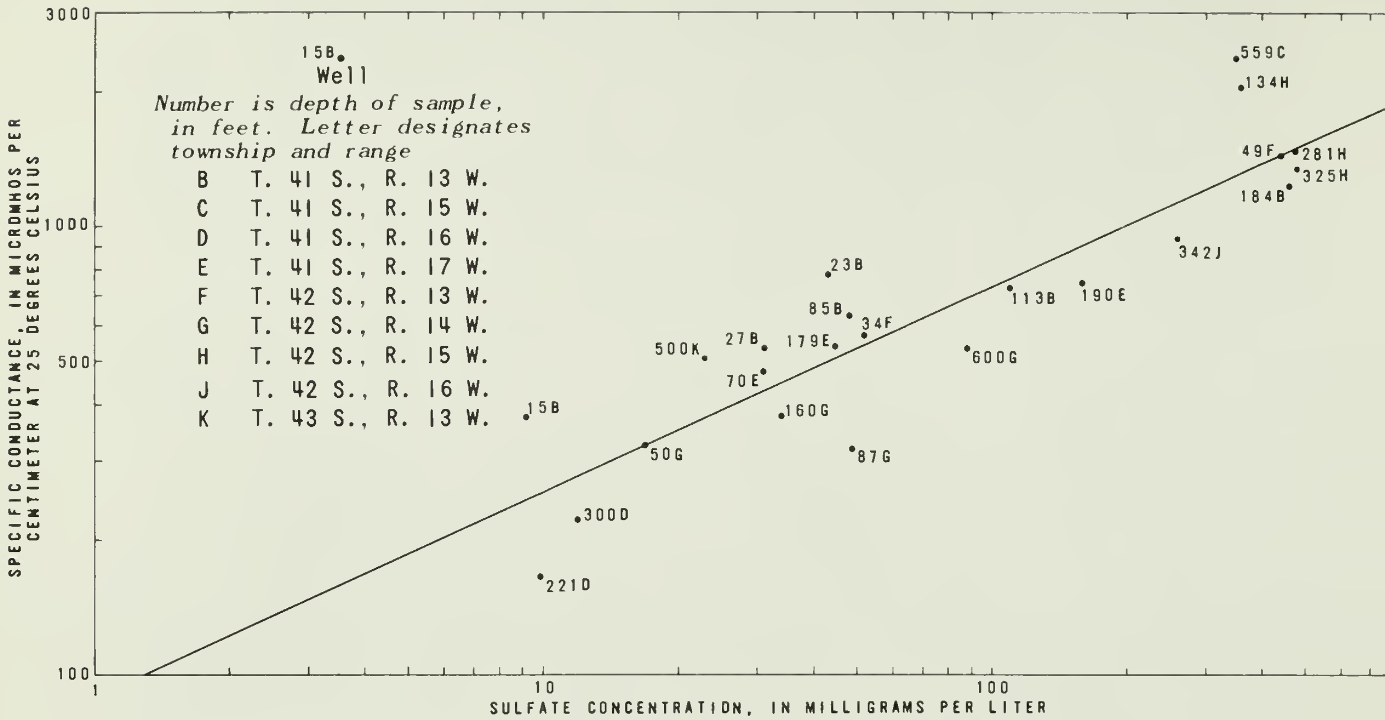


Figure 13.— Relation of sulfate concentration to specific conductance of ground water from the Navajo Sandstone.

The analyses in table 7 indicate that about 92 percent of the wells and springs yield water containing chloride in concentrations less than 250 mg/L and most of these less than 50 mg/L. The one spring and two wells yielding water containing chloride in concentrations exceeding the recommended maximum limit are in the area between the St. George and Washington faults.

About 55 percent of the wells and springs yield water with dissolved-solids concentrations that are less than 500 mg/L (table 7). About 60 percent of the wells and springs yield water with sulfate concentrations that are less than 250 mg/L (table 7). Most of the wells and springs that yield water that does not meet the recommended maximum limits are in the area north of St. George and Washington.

Irrigation

Two important determinants of the usefulness of water for irrigation are the sodium-adsorption ratio (SAR) and the specific conductance. The SAR is a measure of the sodium hazard and the specific conductance is a measure of the salinity hazard. The higher these hazards the more unsuitable the water is for irrigation. According to a classification system by the U.S. Salinity Laboratory Staff (1954, p. 79-81),

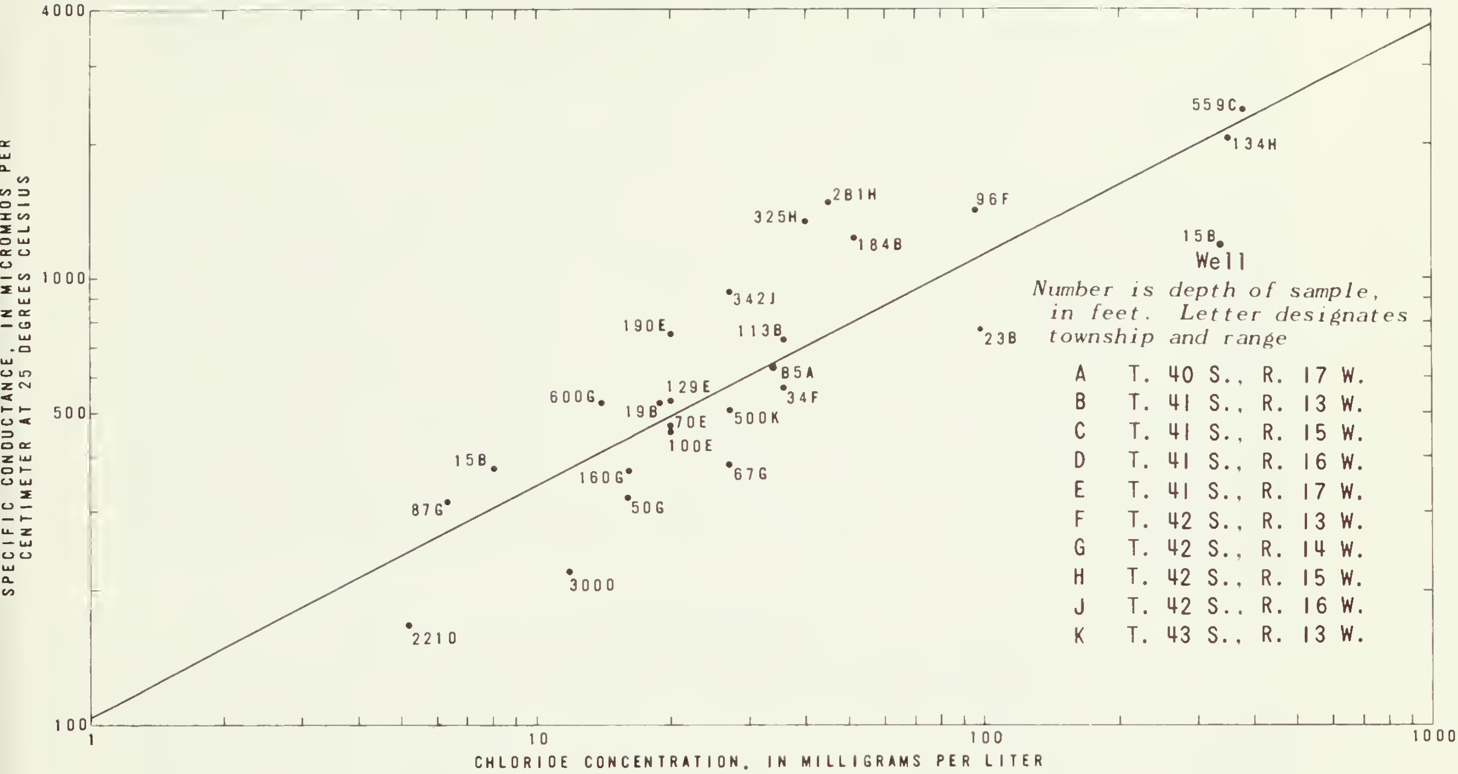


Figure 14.—Relation of chloride concentration to specific conductance of ground water from the Navajo Sandstone.

water with a specific conductance exceeding 750 micromhos/cm at 25°C has a high salinity hazard and if it exceeds 2,250 micromhos/cm, the salinity hazard is very high. About 45 percent of the wells yield water with values of specific conductance exceeding 750 micromhos/cm (table 7); however, only one well yields water with a specific conductance exceeding 2,250 micromhos/cm. These same wells and springs have a low or medium sodium hazard and are mainly in the area north of St. George and Washington.

Chemical types

The most common anions in the ground water of the Navajo Sandstone include bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl) (pl. 3). In order to obtain an insight into the possible sources of ground water, a determination of the relation of the three anions was made by a method described by Hem (1970, p. 237-239). Types of ground water in the project area based on ratios of the common anions, in milliequivalents per liter, are as follows:

1.	Bicarbonate water	$HCO_3/(SO_4 + Cl) \geq 1$
2.	Sulfate water	$SO_4/(HCO_3 + Cl) \geq 1$
3.	Mixed water	No anion dominant

Bicarbonate water is the most common type in the Navajo Sandstone. Sulfate and mixed waters are fairly common, but sulfate is somewhat more common than the mixed type. In some localities, chloride is in significant amounts but is not dominant among the anions of any water analyzed.

Several conclusions can be drawn about the source of water from the relation of the areal distribution of anions (pl. 3) to geology. The sulfate ion dominates, or is in significant amounts, generally in ground water that is in the lower unit of the Navajo Sandstone or in the subsurface along or near a fault. However, the dominance of sulfate in some of the water west of Hurricane is most readily explainable by presuming a source for sulfate in the basaltic intrusive rocks that probably underlie the area in and around Volcano Mountain and that are genetically related to the volcanic rocks at the surface; hydrothermally emplaced sulfur-bearing minerals are fairly common in igneous rocks. The chloride ion is in significant amounts in ground water moving along or near faults north and northeast of St. George and near Leeds; part of this water is thermal.

Temperature

The temperature of ground water from the Navajo Sandstone ranges from 11.0° to 40.0°C. Commonly the range is from 17.0° to 26.0°C. The range for wells is 11.0° to 40.0°C, but that for springs is 17.5° to 24.0°C.

One reason for the large range in temperature is the effect of altitude; lower temperatures are at higher altitudes (Cordova, Sandberg, and McConkie, 1972, p. 38). Another reason is the natural increase of temperature with an increase of depth (temperature gradient). That is, the deeper a well is drilled, the warmer the water encountered.

From a practical standpoint, there are two temperature gradients in the project area; one is between the land surface and the saturated zone, and the other is in the saturated zone. The first gradient (fig. 15) is about 2.0°C per 100 ft (30 m) of depth below land surface, assuming a linear gradient based on the mean annual air temperature and the water temperature at the water table. This gradient is usable for estimating ground-water temperature at the top of the saturated zone at potential well sites if the depth to water is known.

Gradients in the saturated zone based on temperature logs in three deep water wells and on a bottom-hole temperature in one deep oil test are as follows:

	Gradient (°C per 100 ft)
(C-39-13)33ccd-1	0.72
(C-41-16)16cdb-1	.39
(C-42-14)25abb-1	.36
(C-42-15)6dcd-1	.78

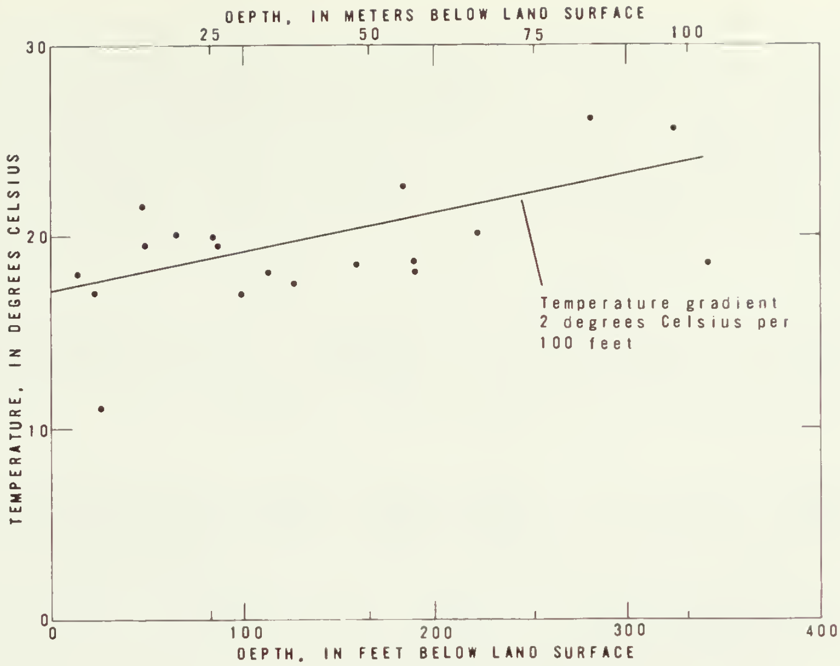


Figure 15.— Relation of temperature of ground water at top of saturated zone to depth to water below land surface in the Navajo Sandstone.

The average of these four gradients is 0.56°C per 100 ft (30 m) of depth. This average probably represents the normal temperature gradient in the saturated part of the Navajo Sandstone of the project area.

Locally high temperatures at wells (C-41-15)32aca-1 and (C-42-15) 10bcd-1 indicate that deep ground water is probably rising along faults. Assuming a gradient of 0.56°C per 100 ft (30 m), the water in well (C-41-15)32aca-1 is estimated to be rising from about 5,800 ft (1,800 m) below land surface. However, if at depth the gradient is steeper than the average of 0.56°C per 100 ft (30 m) as a result of the presence of a hot igneous body fairly close to the land surface, the water would not be rising from 5,800 ft (1,800 m) but from a shallower depth.

POTENTIAL DEVELOPMENT

The Navajo Sandstone in the central Virgin River basin has a favorable potential for additional development by large-discharge wells. In most of the localities where wells have reached the saturated zone, discharge rates, specific capacities, and chemical quality have been satisfactory for such development. The main factors limiting the potential for development include aquifer storage, recharge, the mutual effects of pumping between wells, and the effects of diminution of streamflows. Locally, water quality and temperature are added limiting factors.

The investigation of the Navajo Sandstone in the central Virgin River basin indicated that 2.8 million acre-ft (3,450 hm^3) of ground water is the maximum available to wells by gravity drainage from storage

in the outcropping part of the formation. In developing this resource, perhaps as much as 80 percent of this amount or 2.2 million acre-ft (2,710 hm^3) may be utilized. Another alternative, depending on the water-management policy, might be to utilize only the part replaceable by recharge. If 80 percent of the amount is used, then the resource will be depleted (mined) without consideration of the limits of replacement by recharge or of effects on natural discharge like springflow. If it is planned to use the resource with no long-term depletion, the magnitude of water that could be pumped must be less than or equivalent to the replaceable amount, that is, recharge. The minimum amount of recharge in 1974 was about 17,000 acre-ft (21 hm^3), and only a small percentage of this amount was discharged by wells.

Discharging wells in the project area have two effects on the ground-water reservoir: (1) ground water is diverted from points of natural discharge such as springs, and (2) the potentiometric surface is lowered. Increasing the amount of well discharge will add to these effects. The effects will be most noticeable where wells are close to points of natural discharge or to other wells, and where water is confined in contrast to where it is unconfined. However, a relatively impermeable barrier between two wells or between a well and a point of natural discharge would lessen or negate the effects of discharging wells on other sources of discharge.

Increasing the amount of well discharge also increases the possibility of diverting poor quality water from the lower unit of the Navajo Sandstone and from faulted areas where warm or highly mineralized water is circulating. Such a change in quality is likely in areas that are near or between the St. George and Washington faults.

CONCLUSIONS

The Navajo Sandstone is essentially a quartzose sandstone about 2,000 ft (600 m) in maximum thickness. The formation is practically homogeneous in the size and sorting of its grains.

Recharge is estimated for 1974 to be a minimum of 17,000 acre-ft (21 hm^3). Movement of ground water is generally from the Pine Valley Mountains, Bull Valley Mountains, and the area east of the Hurricane Cliffs toward the Virgin River and its tributaries. Discharge in 1974 was a minimum of 19,000 acre-ft (23 hm^3); about 1,600 acre-ft (2 hm^3) of this amount was from storage in the Gunlock well field. The discharge rate of individual wells averages about 540 gal/min (34 L/s); the specific capacity averages about 16 (gal/min)/ft [3.3 (L/s)/m].

The average effective porosity in the saturated zone is an estimated 17 percent. The average specific yield was computed from aquifer tests to be 4 percent. Based on laboratory analysis, the hydraulic conductivity of outcrop samples has an average value of 2.1 ft/d (0.64 m/d); results of aquifer tests yield an average hydraulic conductivity of 5 ft/d (1.5 m/d).

A significant long-term change in storage has not occurred in a large part of the area. A decrease in storage has occurred in St. George City's Gunlock well field. The maximum amount of ground water in storage available to wells is estimated to be 2.8 million acre-ft (3,450 hm^3), of which perhaps as much as 2.2 million acre-ft (2,710 hm^3) may be recoverable by wells. The hydrologic effects of discharging wells include interference between wells and reduction of springflow and streamflow.

The concentration of dissolved solids and of the principal ions ranges widely; for example, the dissolved solids range from 103 to 1,360 mg/L. Water in the lower unit and in fault zones has the largest amounts of dissolved minerals.

The temperature of ground water ranges from 11.0° to 40.0°C. The average increase of temperature with depth in the saturated zone is 0.56°C per 100 ft (30 m).

The Navajo Sandstone in the central Virgin River basin has a favorable potential for additional development by large-discharge wells. In most localities where wells have reached the saturated zone, discharge rates, specific capacities, and chemical quality have been satisfactory for such development. The main limiting factors of potential development include storage, recharge, and effects of pumping; locally water quality and temperature are added limiting factors.

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Table 6.--Records of selected wells aa of Februsry 1975

Location: See section on numbering system for hydrogeologic-dats sites.
Use of water or well: H, domestic; I, irrigation; P, public supply; S, stock; T, test; U, unused.
Total depth: Reported by driller unless indicsted by m, measured by U.S. Geological Survey personnel (date of measurement in psrentheses).
Diameter of borehole: Msximum diameter only for wells having more than one diameter.
Finish of well: F, perforations and gravel packed; O, open end; P, perforations; X, open hole.
Altitude of potentiometric surface: Oate of messurement other than October 1974 is shown in parentheses; numbers rounded to nearest foot; r, reported.
Oepth to top of Nsvajo Ssndstone: Letters indicate type of cover - A, alluvial terrsce or alluvial fill; C, consolidated sedimentary rocks younger than the Navsjo Sandstone; F, slluvial fsn; C, gravel or boulders; L, lava rock; S, dune sand, some clay or silt layers locally; V, vslley fill.
Oischsrge: Measured by U.S. Geological Survey personnel unless indicsted r, reported by driller or owner at time of construction; e, estimsted; F, flowing.
Specific capscity: 0, vslues determined for 24-hour period; other values determined for periods other than 24 hours.
Remarks snd other data available: C, chemical snalysis in tsble 7; L, geophysicsl log in files of U.S. Ceological Survey; W, periodic water-level messurements in table 8.

Location	Name or owner	Year constructed	Use of water or well	Total depth (ft)	Diameter of borehole (in.)	Depth of casing (ft)	Finish of well	Altitude of land surface (ft above mean sea level)	Altitude of potentiometric surface in October 1974 (ft above mean sea level)	Depth to top of Navajo Sandstone (ft)	Oischarge: Rate (gal/min) and date	Oischarge: Total 1974 (acre-ft)	Specific capacity [(gal/min)/ft]	Remarks and other data available
Wells drilled into the Navajo Sandstone														
(C-39-13)33ccd-1	Sun Oil Co.	1951	U	5,496	17½	-	-	5,240	-	0	-	-	-	Destroyed.
(C-40-14)35aab-1	Leeds Creek well	1973	U	405	16	-	-	4,360	-	16C	-	-	-	Water table not reached; destroyed.
(C-40-16)34cad-1	L. Staheli	1974	U	280	8	-	-	4,565	-	14S	-	-	-	Oo.
(C-41-13)4bab-1	W. Scheuber	1966	H	115	10	-	-	3,680	3,666	0	-	1e	-	C, W.
4bbc-1	H. Ludwig	1970	H	100	8	100	F	3,670	-	0	-	1e	-	C.
5aaa-1	E. Wooten	1960	H	60	14	11	X	3,675	3,649	3S	106 10-30-74	10e	-	C, W.
5adb-1	L. Howard	1969	I	54	14	17	X	3,650	3,632 (Jan. 1975)	3S	85r	0	-	
5adb-2	A. Howard	1974	I	97	8	83	X	3,650	3,629 (Jan. 1975)	25GS	-	0	3	
5bbc-1	Goddsrd and Savage	1972	I	310	8	40	X	3,660	3,588	26E	550 10-10-74	91.7	14D	C, W.
6aac-1	do	1972	T	260	11	31	X	3,700	3,616	27F	50r	0	3	C, L, W.
23bca-1	Ash Creek well	1969	S	1,835	14	140	X	3,040	3,055r (1969)	1,700FC	96F 2-5-75	([1])	-	Orilled into alluvium, Oakota Sandstone, Carmel Formation, and Navajo Sandstone. C.
31acd-1	F. Judd	1973	T	259	5	259	0	3,080	2,899	161AL	200r	0	2	C, L, W.
(C-41-14)15ads-1	U.S. Buresu of Land Management	1963	P	65	6	47	F	3,220	3,190r	0	20r	4e	-	
(C-41-15)30abc-1	F. Hollsnd and M. Cubler	1956	U	215	16	0	-	3,840	-	0	-	0	-	Water table not reached; destroyed.
32aca-1	Terracor	1974	T	600	14	550	0	3,530	3,052 (Nov. 1974)	0	-	0	-	C, L.
(C-41-16)3dbc-1	State of Utah	1969	U	900	6	-	-	4,400	-	15C	-	0	-	Water table not reached; destroyed.
9cba-1	Snow Canyon 2	1974	T	425	16	-	-	3,550	3,263 (Sept. 1974)	0	-	0	-	C, L.
16cdb-1	Snow Canyon 1	1974	T	685	8	-	X	3,440	3,254	0	965 8-13-74	40.0	90	C, L, W.
(C-41-17)7ada-1	Gunlock 4a	1966	T	244m (1969)	16	346	P	3,600	3,382	0	-	0	-	Originally drilled to 375 ft. L, W.
7ddb-1	Gunlock 2	1965	P	500	16	446	F	3,580	3,384	17S	822 7-1-74	92.0	-	C, W.
8cac-1	Gunlock 1	1965	P	500	16	283	F	3,480	3,379 (Jan. 1974)	3S	630 10-28-74	565.6	8	C, W.
8cda-1	Gunlock 4b	1970	P	500	14	-	-	3,460	3,393 (Jan. 1974)	0S	2,000 1-22-74	973.2	220	C, W.
17bdb-1	Gunlock 3	1965	P	626	16	626	F	3,460	3,377 (Jan. 1974)	0	1,620 9-26-74	132.4	14	C, W.
(C-42-13)6bac-1	W. Wilson	1962	U	180	8	-	-	3,035	2,905	22A	-	0	-	
6bac-1	do	1974	U	417	12	100	X	3,035	2,908	22A	-	0	-	W.
7bba-1	do	1958	U	185	8	18	X	2,960	2,913	8S	725r	0	-	C, L, W.
7bbs-1	do	1962	U	127	16	-	X	2,960	2,912	11SL	400r	0	-	C.
7bba-3	do	1965	U	705	16	50	X	2,960	2,909	15S	1,800r	0	-	
7cbb-1	Hydro-Tech Co.	1964	I	129	16	15	X	2,950	2,918 (Nov. 1968)	14S	368 10-10-74	108.0	-	C.
7ccb-1	W. Wilson	1974	I	400	-	-	-	2,950	2,901 (July 1974)	14S	-	0	-	W.
18bcb-1	W. John	1958	U	258	8	18	X	2,980	2,920	4S	-	0	-	L, W.
18bcb-2	do	1959	U	194	14	17	X	2,980	2,921 (June 1974)	15S	850r	0	-	L.
(C-42-14)1add-1	W. Wilson	1969	U	300	14	145	X	2,960	2,858	161AL	-	0	-	
12ada-1	do	1974	I	300	12	101	X	2,916	2,892 2,925	36S	420 10-23-74	2.6	6	C.
12dbb-1	Oixie Springs Farm	1964	I	140	16	23	X	2,925	2,891	6S	156 8-4-70	0	2	C.
12dda-1	W. Wilson	1974	I	425	12	40	X	2,940	2,904	41S	400 10-23-74	15.8	120	C, W.
15cda-1	E. Willard	1971	H	272	14	-	X	2,875	2,800 (Jan. 1971)	0	50r	0	3	
15dab-1	R. Graff	1974	I	200	14	12	X	2,910	2,821 (July 1974)	35V	200r	20e	-	
25abb-1	Terracor 3	1970	T	720	8	4	X	3,010	2,937	0	375	0	4	C, L, W.
25adc-2	G. Woodbury	1959	S	165	10	5	X	3,030	2,931 (Aug. 1970)	4S	-	0		
26bbb-1	Terrscor 2	1970	T	645	8	5	X	3,035	2,947	4S	250r	0	2	L, W.
34cad-1	Terracor 1	1970	T	735	8	11	X	3,515	3,080r (July 1970)	10S	-	0	-	C.
(C-42-15)6dcc-1	City Creek No. 1	1973	T	700	16	30	X	3,296	3,042	0	1,320 7-28-73	166	21D	C, L, W.
6dcd-1	City Creek No. 2	1974	T	900	24	50	X	3,308	3,040 (Sept. 1974)	0	470 1-29-75	9	200	C, L.
10bcd-1	Wsshington City	1972	T	650	16	20	X	3,020	2,940	20S	1,000 5-18-74	44	10D	C, L, W.
15abb-1	F. Sullivan	1970	U	231m (1973)	5	30	X	2,900	2,866	5S	250r	0	6	L.

Table 6.--Records of selected wells as of February 1975--Continued

Location	Name or owner	Year constructed	Use of water or well	Total depth (ft)	Diameter of borehole (in.)	Depth of casing (ft)	Finish of well	Altitude of land surface (ft above mean sea level)	Altitude of potentiometric surface in October 1974 (ft above mean sea level)	Depth to top of Navajo Sandstone (ft)	Discharge: Rate (gal/min) and date	Discharge: Total 1974 (acre-ft)	Specific capacity [(gal/min)/ft]	Remarks and other data available
Wells drilled into the Navajo Sandstone--Continued														
(C-42-15)20cdb-1	St. George City	1955	U	100	12	26	X	2,920	2,906	0	584r	0	-	L.
(C-42-16)1ccd-1	Twist Hollow	1974	T	365	12	4	X	3,240	2,988	4S	-	0	-	Water table in Kayenta Formation. C, L.
(C-43-13)5bdd-1	Spillsbury Land and Livestock Co.	1956	S	530	6	46	X	3,420	-	46S	-	3e	-	C.
21caa-1	W. Spendlove	1962	S	185	6	50	X	3,300	3,140r (Sept. 1962)	55A	25	0	-	Water table is in underlying Kayenta Formation.
Wells drilled into formations other than the Navajo Sandstone														
(C-40-13)27bdb-2	Anderson Ranch	1958	S	300	6	-	-	3,840	3,595	-	21r	-	-	Aquifer is valley fill.
(C-41-14)28dab-1	U.S. Bureau of Land Management	1966	U	151m (1974)	6	19	P	3,280	3,192	-	-	-	-	Aquifer is Kayenta Formation.
(C-41-16)28bca-1	O. Snow	1963	U	300	6	28	-	3,200	3,072	-	-	-	-	Do.
(C-42-13)17dcd-1	W. Wilson	1970	U	230m (1974)	12	-	-	3,300	3,075 (July 1974)	-	-	-	-	Aquifer is valley fill.
22bbb-1	do	1973	U	500	12	428	0	3,360	3,063 (Sept. 1974)	-	-	-	-	Do.
(C-42-14)1bac-1	L. Jones	1973	1	400	16	-	-	2,880	2,840 (Aug. 1974)	-	530 5-10-74	-	-	Aquifer is Moenave Formation.
15baa-1	M. Fawcett	1960	U	140	14	-	P	2,800	2,686 (July 1974)	-	-	-	-	Aquifer is valley fill.
(C-42-14)11dcc-1	Washington City	1972	P	600	8	100	X	2,930	2,800	-	60r	-	-	Aquifer is Kayenta Formation.
21bad-1	C. Helm	1965	U	200	8	38	X	2,860	2,840	-	20r	-	-	Aquifer is Kayenta Formation. L.
(C-42-16)5bbb-1	W. Hafen	1963	I	110	16	36	X	3,060	3,032	-	55r	-	-	Aquifer is Chinle Formation.
23aad-2	W. Thompson	1969	H	140	14	30	X	2,860	2,827	-	-	-	-	Aquifer is Kayenta Formation.

[1]Well flows continuously and the total 1974 discharge (150 acre-ft) is based on the assumption that the measured discharge is a constant rate. The contribution from the Navajo Sandstone is probably small and is assumed to be 10 percent of the total or 15 acre-ft.

Location: See section on numbering system for hydrogeologic-data sites.
Dissolved solids: Determined values by the U.S. Geological Survey are residue on evaporation at 180°C; by the Utah State Department of Health are at 110°C; and by the U.S. Bureau of Reclamation and the Ford Chemical Laboratory, Inc., are at 105°C. Calculated values are indicated by c.
Agency making analysis: BR, U.S. Bureau of Reclamation; FC, Ford Chemical Laboratory, Inc., Salt Lake City, Utah; GS, U.S. Geological Survey; SH, Utah State Department of Health

Location	Date of sample	Temperature (°C)	Approximate depth of sample collected (ft)	Milligrams							
				Dissolved silica (SiO_2)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Dissolved sulfate (SO_4)
											WELLS
(C-41-13)4bab-1	10-30-68	18.0	15	26	35	24	10[1]	-	232	0	9.2
4bbc-1	1-10-75	11.0	27	36	54	21	26	3.3	257	-	31
5aaa-1	7- 5-74	17.0	23	32	78	19	42	1.5	212	0	43
5bbc-1	7- 3-74	18.0	113	23	75	31	28	2.3	246	0	110
	10- 8-74	18.5	190	23	77	29	28	2.2	248	-	110
	10-10-74	18.5	190	23	76	29	30	2.6	247	-	120
	10-11-74	18.5	190	24	80	29	29	2.3	248	-	110
6aac-1	11-16-74	20.0	85	22	62	22	32	2.7	262	-	48
23bca-1	2- 5-75	17.5	([2])	26	180	110	64	6.0	216	-	750
31acd-1	11-17-74	22.5	184	3.5	120	53	55	7.9	112	-	460
(C-41-15)32aca-1	11-15-74	40.0	559	20	110	19	340	29	226	-	350
(C-41-16)9cba-1	9-24-74	-	300	12	26	7.5	7.2	2.8	97	-	12
16cdb-1	7-19-74	20.0	221	18	21	6.4	4.0	1.8	81	-	9.9
	7-24-74	19.0	216	17	19	7.4	3.9	1.7	81	-	8.3
	8-10-74	19.0	323	17	19	6.9	4.3	1.8	81	-	8.1
(C-41-17)7ddb-1	3-29-65	-	178	18	109	27	13	2.7	245	.27	166
	5- 1-74	18.0	190	18	100	27	14	2.5	241	0	160
8cac-1	5- 5-65	17.0	100	19	66	14	6.0	.6	233	3	20
8cda-1[3]	1-15-73	-	70	29	77	10	16	2.0	244	.43	35
	1-22-74	17.5	129	29	70	15	17	2.0	255	0	45
	1-22-74	17.5	137	29	72	15	17	1.8	254	0	45
	1-23-74	17.5	160	29	70	14	17	1.9	250	0	43
	1-27-74	17.5	176	30	68	14	16	1.9	256	0	39
	1-29-74	17.5	181	30	68	14	15	1.7	249	0	36
	2- 6-74	17.0	193	28	69	13	16	2.4	240	0	33
17bdb-1	12- 2-66	-	70	16	57	16	38	4.0	244	0	31
(C-42-13)7bba-1	11-17-74	21.5	49	18	140	48	90	5.2	147	-	440
7bba-2	11-17-74	21.0	49	17	140	58	83	8.2	152	-	500
7cbb-1	11-23-65	-	34	-	17	38	7.4	1.6	119	0	52
(C-42-14)12ada-1	10-23-74	19.5	87	15	32	16	10	1.7	112	-	49
12dbb-1	9-11-68	20.0	67	-	-	-	-	-	-	-	-
12dda-1	5-21-74	19.5	-	15	33	16	8.6	1.7	138	0	20
	10-23-74	19.5	50	15	33	17	6.6	1.6	138	-	17
	10-27-74	19.5	75	15	32	17	6.2	1.7	138	-	15
	10-30-74	19.0	74	15	33	17	6.1	1.7	137	-	15
25abb-1[4]	3-19-75	18.5	160	4.4	31	18	11	2.3	143	0	34
34cad-1[5]	7- 9-70	-	600	-	40	33	.3	.2	161	0	88
(C-42-15)6dcc-1[6]	2-14-73	-	260	3.5	77	15	98	5.5	101	0	352
	8- 4-73	25.5	325	19	100	17	170	19	193	0	480
	8- 8-73	26.0	323	19	100	17	170	20	198	0	470
	8-21-73	26.0	318	19	97	17	160	20	155	0	500
	8-22-73	26.0	353	19	100	17	170	20	197	0	500
6dcd-1[7]	9-18-74	-	270	3.9	106	16	230	30	210	<.01	610
	1-28-75	26.0	281	19	99	18	170	19	201	-	480
	1-30-75	26.0	291	20	99	17	180	20	199	-	490
	1-31-75	26.0	291	19	96	19	170	20	200	-	480
	2- 1-75	26.0	294	19	96	18	180	19	200	-	480
	2- 1-75	26.0	324	19	96	18	180	19	199	-	480
	2- 2-75	26.0	326	19	96	19	170	20	200	-	490
10bcd-1	5-18-74	27.5	134	22	110	27	290	26	225	0	360
	5-18-74	27.5	162	22	100	22	290	26	224	0	330
	5-19-74	28.5	185	22	100	22	290	26	222	0	330
	5-23-74	29.0	190	22	100	22	280	25	223	0	320
	5-26-74	29.0	190	22	100	23	290	26	222	0	330
	5-26-74	29.0	242	22	100	22	290	25	223	0	330
	5-28-74	29.0	196	22	100	22	290	26	222	0	330
(C-42-16)1ccd-1	11-14-74	18.5	342	15	65	14	100	10	172	-	260
(C-43-13)5bdd-1	3-16-66	-	500	-	41	16	5.1	1.6	131	6	23

per liter								Micrograms per liter						
Dissolved chloride (Cl)	Oissolved nitrate (NO3) + nitrite (NO2) as N	Oissolved nitrate (NO3)	Oissolved phosphate (PO4)	Dissolved fluoride (F)	Dissolved solids	Hardness (Ca,Mg)	Noncarbonate hardness	Dissolved boron (B)	Dissolved iron (Fe)	Dissolved manganese (Mn)	Specific conductance (micromhos/cm at 25°C)	Sodium-adsorption ratio	pH	Agency making analysis
8.1	-	0.8	-	-	227	188	0	20	-	-	372	0.3	8.0	GS
19	1.7	-	0.12	0.2	325	220	11	100	-	-	531	.8	7.7	GS
98	.96	-	.03	.2	423c	270	99	90	10	0	768	1.1	7.8	GS
36	.39	-	.03	.3	429c	320	110	110	60	20	723	.7	7.7	GS
37	.32	-	.06	.1	430c	310	110	100	30	0	711	.7	7.5	GS
39	.34	-	.06	.1	443c	310	110	110	20	0	717	.7	7.5	GS
39	.37	-	.06	.2	438c	320	120	100	30	10	716	.7	7.6	GS
34	2.0	-	.03	.3	361c	250	31	40	-	-	635	.9	8.1	GS
74	4.6	-	.03	.6	1,340	900	730	580	-	-	2,000	.9	7.4	GS
51	.03	-	.03	.2	806c	520	430	190	-	-	1,220	1.1	7.2	GS
380	.11	-	.03	1.3	1,360	350	170	170	-	-	2,380	7.9	7.3	GS
12	.13	-	.00	.2	129c	96	16	850	-	-	220	.3	7.8	GS
5.2	.30	-	.09	.2	108c	78	12	0	-	-	167	.2	8.2	GS
5.1	.10	-	.09	.1	103c	78	11	150	-	-	166	.2	7.8	GS
5.0	.28	-	.18	.1	104c	76	9	170	-	-	166	.2	7.9	GS
23	-	4.7	-	.3	511	382	181	190	190	-	660	.3	7.3	SH
20	.95	-	.06	.2	465c	360	160	100	300	20	745	.3	7.5	GS
20	-	.5	-	.3	283	221	25	200	50	-	455	.2	8.4	SH
18	-	.0	.2	.19	308	232	-	65	.0	.00	470	.5	7.5	SH
20	.05	-	.03	.20	324	240	27	60	10	250	538	.5	7.8	GS
19	.03	-	.03	.0	325	240	33	50	290	340	529	.5	8.1	GS
19	.05	-	.06	.2	318	230	27	50	60	240	524	.5	8.1	GS
19	.03	-	.09	.2	315	230	17	50	20	210	511	.5	7.8	GS
18	.00	-	.03	.2	306	230	23	50	30	190	502	.4	7.7	GS
18	.03	-	.03	.2	298	230	29	70	50	120	493	.5	7.6	GS
20	-	.2	-	.4	286	207	7	-	30	-	470	1.1	7.5	SH
96	1.3	-	.03	.3	916	550	430	210	-	-	1,420	1.7	7.5	GS
93	.69	-	.03	.4	978	590	460	90	-	-	1,450	1.5	7.7	GS
36	-	3.7	-	1.3	215	200	102	50	-	-	570	.2	7.6	BR
6.3	1.7	-	.03	.5	193	150	54	50	-	-	318	.4	7.8	GS
27	-	-	-	-	-	-	-	-	-	-	383	-	-	GS
18	2.8	-	.03	.2	193	150	35	40	-	0	321	.3	7.9	GS
16	2.6	-	.03	.2	186	150	39	5	-	-	323	.2	7.7	GS
14	2.6	-	.03	.2	181	150	37	0	-	-	309	.2	7.9	GS
14	2.6	-	.03	.2	181	150	40	0	-	-	309	.2	7.9	GS
16	-	2.6	.18	.02	256	152	-	<10	100	<10	371	.4	7.7	FL
14	-	.65	.88	.45	341	248	-	20	220	10	532	.01	7.8	FL
10	-	.95	.60	1.5	659	257	-	0	180	0	1,029	2.7	7.3	FL
40	.20	-	.03	2.2	944	320	160	760	150	10	1,340	4.1	7.0	GS
40	.13	-	.03	2.5	938	320	160	720	80	10	1,360	4.1	7.3	GS
41	.17	-	.03	2.4	934	310	190	670	50	10	1,370	3.9	7.0	GS
41	.21	-	.03	2.4	968	320	160	720	80	10	1,360	4.1	7.1	GS
42	-	.95	.33	1.8	1,240	329	-	10	180	50	1,798	5.5	7.2	FL
45	.20	-	.03	2.3	953	320	160	630	-	-	1,475	4.1	6.9	GS
41	.05	-	6.4	2.4	975	320	150	620	-	-	1,750	4.4	7.0	GS
48	.20	--	.03	2.4	955	320	150	670	-	-	1,500	4.2	7.0	GS
48	.19	-	.06	2.4	963	310	150	660	-	-	1,500	4.4	7.0	GS
45	.18	-	.03	2.4	959	310	150	630	-	-	1,550	4.4	7.0	GS
45	.24	-	.03	2.4	962	320	150	670	-	-	1,550	4.2	7.0	GS
350	.33	-	.03	1.1	1,300	390	200	530	-	0	2,050	6.4	7.4	GS
340	.10	-	.09	1.1	1,240	340	160	510	-	20	2,030	6.8	7.3	GS
350	.18	-	.03	1.1	1,250	340	160	530	-	0	2,040	6.8	7.3	GS
340	.18	-	.12	1.1	1,220	340	160	540	-	10	2,020	6.6	7.2	GS
350	.11	-	.09	1.1	1,250	340	160	550	-	0	2,030	6.8	7.2	GS
340	.08	-	.03	1.1	1,240	340	160	510	-	20	2,040	6.8	7.2	GS
350	.11	-	.03	1.1	1,250	340	160	520	-	0	2,050	6.8	7.1	GS
27	.71	-	.09	.6	580	220	79	20	-	-	935	2.9	7.2	GS
27	-	-	-	.3	229	167	50	360	-	-	502	.2	8.3	BR

Table 7.--Chemical analyses and temperature of water

Location	Date of sample	Temperature (°C)	Approximate depth of sample collected (ft)	Milligrams: Dissolved silica (SiO_2)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Dissolved sulfate (SO_4)
SPRINGS											
(C-41-16)34bda-S1	5-15-64	-	Surface	14	37	13	13	3.8	121	0	45
	8-28-68	21.0	do	-	-	-	-	-	-	-	-
(C-41-17)17dbd-S1	12-13-73	17.5	do	21	94	30	12	2.0	228	0	150
(C-42-15)10a-S1[8]	4-10-69	-	do	13	68	19	62	12	194	.95	152
14bcb-S1	10-16-68	20.0	do	19	63	35	-	-	220	0	101
15aaa-S1	7-14-62	-	do	12	62	22	8.6	4.7	186	0	95
	10-16-68	24.0	do	-	-	-	-	-	-	-	-
15bba-S1	3-30-66	23.5	do	-	100	22	283	25	206	4	415
	10-16-68	21.0	do	-	-	-	-	-	-	-	-
16ddd-S2	1-18-74	20.0	do	20	110	26	190	18	249	0	460
19cba-S1	2-11-74	19.0	do	17	93	28	130	13	202	0	400
20bdb-S1	6- 4-74	20.0	do	18	99	24	150	13	221	0	420
20cad-S1	4- 1-66	([9])	do	-	60	40	169	16	201	-	456
(C-42-16)13dcb-S1	1-21-74	20.0	do	17	78	23	120	10	191	0	320
STREAMS											
(C-41-13)27baa	2- 3-75	-	-	16	140	43	230	18	309	-	340
30dbb	2- 3-75	-	-	17	130	43	220	18	281	-	320
(C-41-17)17acc	1-29-74	-	-	19	45	13	14	2.7	192	0	24
(C-41-19)17dcd	2- 4-74	13.5	-	21	70	18	16	2.7	223	0	48

[1]Sodium plus potassium.

[2]Flowing well. Water is probably from several formations between the depths of about 180 and 1,835 feet; these formations include the water table downward the Dakota Sandstone, Carmel Formation, and Navajo Sandstone.

[3]Analysis includes 0.00 μg/L zinc, 22 μg/L selenium; 10 μg/L arsenic, and 0.00 μg/L mercury.

[4]Analysis includes 10 μg/L zinc, selenium, and arsenic and 1.0 μg/L mercury.

[5]Analysis includes 0 μg/L zinc and arsenic.

[6]Analysis includes 0 μg/L zinc, selenium, arsenic, and mercury.

[7]Analysis includes 30 μg/L zinc and 10 μg/L selenium, arsenic, and mercury.

[8]Analysis includes 0.04 μg/L zinc, 0.00 μg/L selenium, and 0.01 μg/L arsenic.

[9]19.0°C on 1-18-74.

from selected wells, springs, and streams--Continued

per liter								Micrograms per liter						
Dissolved chloride (Cl)	Dissolved nitrate (NO3) + nitrite (NO2) as N	Dissolved nitrate (NO3)	Dissolved phosphate (PO4)	Dissolved fluoride (F)	Dissolved solids	Hardness (Ca,Mg)	Noncarbonate hardnesa	Dissolved boron (B)	Dissolved iron (Fe)	Dissolved manganeae (Mn)	Specific conductance (micromhos/cm at 25°C)	Sodium-adsorption ratio	pH	Agency making analysis
15	-	1.4	-	0.6	226	146	47	160	20	-	345	0.4	7.8	SH
13	-	-	-	-	-	-	-	-	-	-	360	-	-	GS
23	1.8	-	.18	.4	453	360	170	110	30	20	726	.3	8.1	GS
138	-	.1	.9	.6	638	248	-	350	.00	.00	1,115	1.7	8.0	SH
29	-	9.4	-	-	435	300	120	100	-	-	673	.4	8.0	GS
10	-	3.2	-	.3	328	243	91	60	60	-	516	.2	7.9	SH
8.0	-	-	-	-	-	-	-	-	-	-	487	-	-	GS
285	-	-	-	1.6	1,240	340	163	800	-	-	2,010	6.7	-	BR
295	-	-	-	-	-	-	-	-	-	-	2,010	-	-	GS
96	.18	-	.00	1.5	1,050	380	180	550	30	0	1,550	4.2	8.0	GS
39	.40	-	.03	.8	823	350	180	450	40	50	1,220	3.0	7.1	GS
44	.10	-	.06	1.0	879	350	160	480	60	0	1,310	3.5	7.4	GS
48	-	-	-	1.9	889	314	149	450	-	-	1,320	4.1	8.2	BR
30	.74	-	.00	.6	697	290	130	470	40	0	1,060	3.1	8.1	GS
320	0.54	-	0.03	0.5	1,260	530	270	470	-	-	2,060	4.4	7.7	GS
310	.54	-	.03	.4	1,200	500	270	440	-	-	2,000	4.3	7.6	GS
15	.00	-	.03	.2	228	170	8	70	30	0	385	.5	8.3	GS
22	.03	-	.03	.3	308	250	66	80	20	60	519	.4	7.8	GS

Table 8.--Water levels in selected observation wells

Water levels are in feet below land-surface datum.
An asterisk (*) immediately after a measurement indicates that the measurement was made by driller; all other measurements were made by the U.S. Geological Survey.

(C-41-13)4bab-1	
July 5, 1974	15.73
Oct. 30	14.27
Jan. 10, 1975	14.24
(C-41-13)5aaa-1	
July 5, 1974	23.30
Oct. 30	26.06
Jan. 10, 1975	23.22
(C-41-13)5bbc-1	
Oct. 15, 1974	77.88
Oct. 16	76.77
Oct. 18	75.67
Oct. 22	74.06
Oct. 31	72.06
Nov. 16	69.50
Jan. 7, 1975	66.32
(C-41-13)6aac-1	
Oct. 15, 1974	84.27
Oct. 18	83.95
Oct. 31	83.48
Nov. 16	82.85
Jan. 7, 1975	81.73
(C-41-13)31acd-1	
Nov. 17, 1973	181.51
Dec. 3	181.53
July 3, 1974	181.63
Sept. 27	181.48
Oct. 29	181.40
Nov. 17	181.37
Jan. 8, 1975	181.00
(C-41-16)16cdb-1	
June 3, 1974	183.31
July 1	184.17
Sept. 24	187.12
Oct. 15	186.31
Oct. 31	185.97
Nov. 14	185.57
Nov. 15	185.60
Jan. 5, 1975	185.23
Jan. 9	184.99
(C-41-13)16cdb-1 - Continued	
Feb. 4, 1975	184.88
(C-41-17)7ada-1	
Feb. 25, 1966	203 *
Oct. 22, 1969	206.23
July 18, 1973	212.14
July 24	212.32
Aug. 9	211.64
Sept. 7	211.98
Oct. 4	212.75
Nov. 16	211.60
Nov. 30	211.31
Jan. 15, 1974	210.64
Jan. 17	210.48
Jan. 21	210.60
Feb. 8	210.81
May 1	214.37
May 15	215.50
June 1	215.86
July 1	217.30
July 26	219.28
Oct. 28	218.19
Nov. 18	217.76
Jan. 5, 1975	216.53
Feb. 4	216.02
(C-41-17)7ddb-1	
Mar. 17, 1965	178 *
Jan. 17, 1974	187.90
Jan. 19	187.85
Jan. 21	187.85
Jan. 22	188.11
Jan. 23	187.96
Jan. 24	187.85
Jan. 25	187.74
Jan. 26	187.47
Jan. 27	187.87
Jan. 28	187.76
Jan. 29	187.76
Jan. 30	187.63
Jan. 31	187.71
Feb. 1	187.45
Feb. 2	187.81
Feb. 3	187.84

Table 8.--Water levels in selected observation wells--Continued

(C-41-17)7ddb-1 - Continued

Feb. 4, 1974	187.66
Feb. 5	187.52
Feb. 6	187.66
Feb. 8	187.88
Feb. 9	187.74
Feb. 10	187.58
Feb. 13	187.41
Sept. 26	199.88
Oct. 28	195.44
Jan. 5, 1975	193.51

(C-41-17)8cac-1

Dec. 15, 1964	92 *
July 16, 1968	100.00
Nov. 30, 1973	103.28
Dec. 3	103.29
Dec. 4	103.08
Dec. 7	103.01
Dec. 11	102.46
Dec. 13	102.12
Jan. 15, 1974	100.96
Jan. 17	100.70
Jan. 19	100.58
Jan. 21	100.56
Jan. 22	100.89
Feb. 6	108.81
Jan. 5, 1975	114.83

(C-41-17)8cda-1

June 22, 1970	71.10
Nov. 16, 1973	68.82
Nov. 19	68.68
Nov. 30	68.17
Dec. 3	68.21
Dec. 4	68.49
Dec. 7	68.01
Dec. 11	67.70
Dec. 13	67.07
Jan. 15, 1974	66.89
Jan. 17	66.73
Jan. 19	66.59
Jan. 21	66.65
Jan. 22	66.88
Sept. 26	84.89
Jan. 5, 1975	78.30
Feb. 4	78.40

(C-41-17)17bdb-1

Oct. 8, 1965	76 *
Nov. 30, 1973	83.34

(C-41-17)17bdb-1 - Continued

Dec. 3, 1973	83.44
Dec. 4	83.33
Dec. 7	83.42
Dec. 11	83.15
Dec. 13	82.94
Jan. 15, 1974	82.78
Jan. 17	82.60
Jan. 19	82.53
Jan. 21	82.58
Jan. 22	82.83
Oct. 28	90.72
Jan. 5, 1975	90.80
Feb. 4	90.04

(C-42-13)6bac-1

July 3, 1974	130.33
Sept. 25	130.30
Oct. 29	130.22
Jan. 8, 1975	130.28
Feb. 5	130.20

(C-42-13)7bba-1

Dec. 3, 1973	46.59
Jan. 15, 1974	46.62
Jan. 30	46.55
Feb. 19	46.43
May 3	46.47
July 2	46.57
Sept. 25	46.99
Sept. 27	46.88
Oct. 2	46.94
Oct. 4	46.87
Oct. 8	46.88
Oct. 10	46.87
Oct. 12	46.98
Oct. 14	46.93
Oct. 16	46.88
Oct. 18	47.00
Oct. 22	47.14
Oct. 23	46.99
Oct. 25	47.00
Nov. 17	46.94
Jan. 7, 1975	46.78
Feb. 5	46.95

(C-42-13)7ccb-1

Apr. 30, 1974	48.34
May 30	48.48
July 2	48.92
Sept. 25	50.11

Table 8.--Water levels in selected observation wells--Continued

(C-42-13)7ccb-1 - Continued	
Oct. 10, 1974	50.07
Oct. 12	50.11
Oct. 14	50.15
Oct. 16	50.11
Oct. 18	50.20
Oct. 22	50.15
Oct. 23	50.26
Jan. 7, 1975	49.54
Feb. 5	49.47

(C-42-13)18bcb-1	
Aug. 2, 1973	59.67
Oct. 12	59.77
Nov. 13	59.54
Nov. 17	59.63
Nov. 20	59.62
Nov. 28	59.81
Dec. 1	59.53
Dec. 2	59.73
Dec. 3	59.68
Dec. 6	59.81
Dec. 7	59.76
Dec. 10	59.64
Dec. 14	59.69
Jan. 15, 1974	59.68
Jan. 16	59.64
Jan. 30	59.56
Feb. 19	59.46
Apr. 30	59.56
May 10	59.50
May 28	59.52
May 29	59.46
May 30	59.53
May 31	59.59
June 1	59.52
June 7	59.33
June 26	59.62
June 28	59.60
July 2	59.53
Sept. 25	59.69
Oct. 2	59.61
Oct. 18	59.66
Oct. 22	59.65
Oct. 23	59.68
Nov. 17	59.59
Jan. 7, 1975	59.41
Jan. 8	59.35
Feb. 3	59.48

(C-42-14)12dda-1	
Jan. 15, 1974	34.80

(C-42-14)12dda-1 - Continued	
Jan. 30, 1974	34.61
Feb. 19	34.56
Apr. 30	35.04
May 10	34.99
May 21	35.16
May 30	35.05
June 28	35.30
July 2	35.20
Sept. 25	35.74
Sept. 27	35.53
Oct. 2	35.61
Oct. 4	35.53
Oct. 8	35.57
Oct. 10	35.65
Oct. 12	35.76
Oct. 14	35.70
Oct. 16	35.70
Oct. 18	35.75
Oct. 22	35.72
Oct. 23	35.80
Jan. 7, 1975	35.51
Feb. 5	34.45

(C-42-14)25abb-1	
Jan. 16, 1974	73.56
Jan. 26	73.40
Jan. 30	73.45
Feb. 19	73.35
Apr. 30	73.42
June 1	73.03
June 28	73.50
July 2	73.43
Sept. 25	73.53
Oct. 24	73.45
Nov. 22	73.40
Jan. 7, 1975	74.84

(C-42-14)26bbb-1	
Jan. 16, 1974	87.57
May 3	87.45
June 1	87.49
July 2	87.47
Sept. 25	87.67
Oct. 30	87.60
Jan. 8, 1975	87.18

(C-42-15)10bcd-1	
July 24, 1973	79.77
July 25	79.55
July 26	79.66
July 27	79.82

Table 8.--Water levels in selected observation wells--Continued

(C-42-15)10bcd-1 - Continued	
July 28, 1973	79.77
July 29	79.71
July 30	79.80
July 31	79.80
Aug. 2	79.79
Aug. 3	79.80
Aug. 4	79.66
Aug. 5	79.75
Aug. 7	79.80
Aug. 8	79.81
Aug. 9	79.71
Aug. 10	79.80
Aug. 11	79.73
Aug. 12	79.73
Aug. 14	79.81
Aug. 17	79.79
Aug. 21	79.79
Aug. 27	79.78
Aug. 31	79.73
Sept. 7	79.68
Sept. 17	79.83
Sept. 19	79.71
Oct. 3	79.85
Oct. 9	79.83
Nov. 13	79.71
Dec. 7	79.73
Jan. 15, 1974	79.69
Feb. 8	79.62
Feb. 18	79.75
Apr. 30	79.77
May 10	79.74
May 15	79.71
May 16	79.63
May 17	79.66
May 18	79.59
June 26	80.65
July 4	80.48
Sept. 25	79.88
Oct. 26	79.73
Jan. 4, 1975	79.55

(C-42-15)6dcc-1	
July 17, 1973	261.93
July 25	255.81
Oct. 2	256.70
Oct. 10	256.50
Nov. 13	255.69
Nov. 19	255.73
Dec. 5	255.59
Dec. 13	255.32
Jan. 17, 1974	255.18
Jan. 25	254.57
Jan. 28	254.94
Jan. 30	254.91
Feb. 9	254.87
May 1	254.56
June 4	254.50
June 26	254.42
July 4	254.60
Sept. 24	254.42
Oct. 15	254.62
Oct. 24	254.04
Nov. 12	256.34
Nov. 13	256.37
Nov. 15	256.26
Nov. 18	256.27
Nov. 19	256.54
Nov. 20	254.59
Nov. 21	254.41
Jan. 3, 1975	254.49
Jan. 4	254.28
Jan. 5	254.39
Jan. 6	254.27
Jan. 10	254.37
Jan. 27	254.29
Jan. 29	254.68
Feb. 7	255.31

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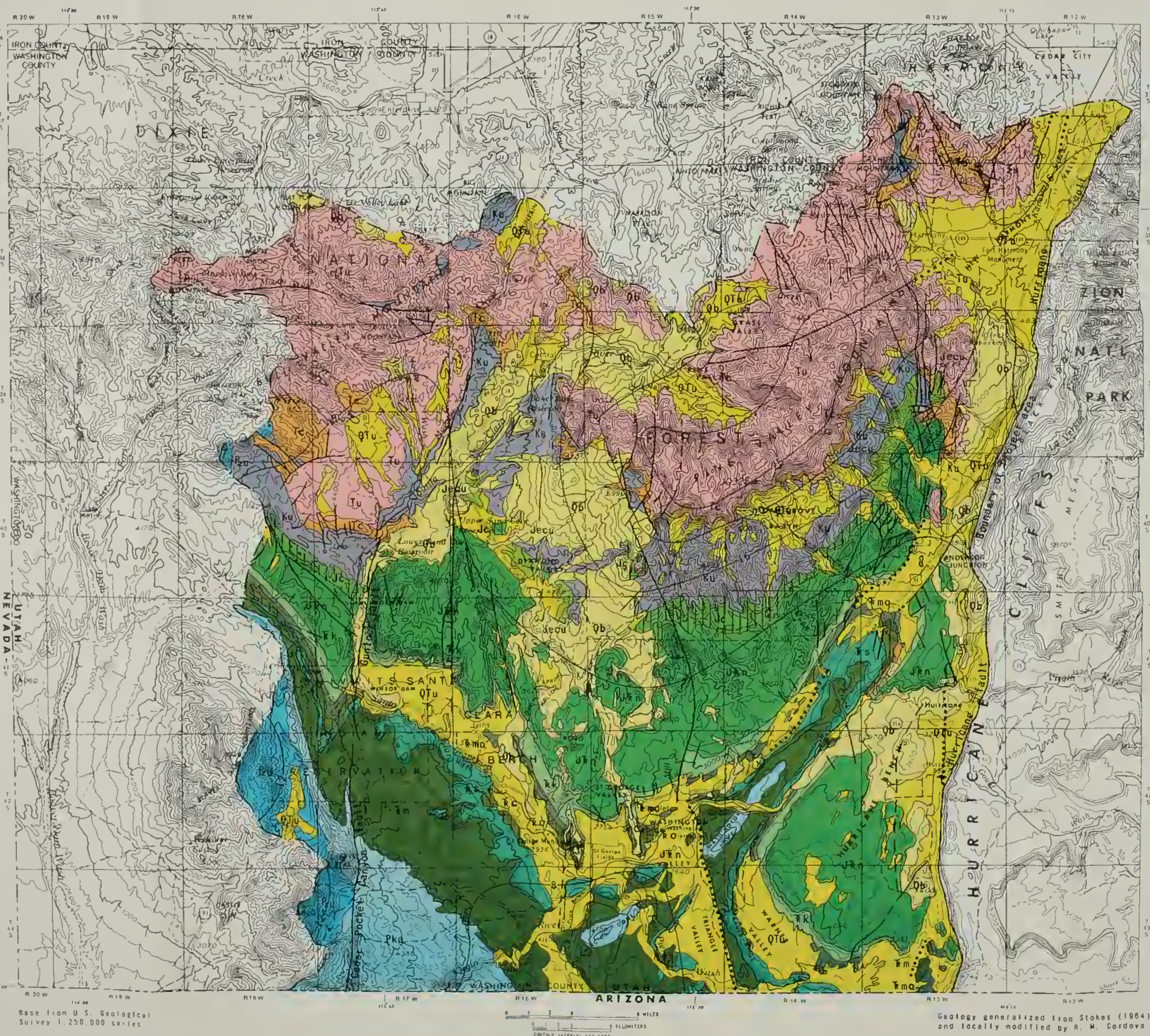


EXPLANATION

Cenozoic

QUATERNARY

Qb — Basalt, some pyroclastics

TERTIARY and QUATERNARY

QTu — Alluvial fans and terraces, channel-fill deposits, sand dunes, landslides, talus, mudflows, and valley-fill deposits

TERTIARY

Tu — Tertiary sedimentary and igneous rocks undifferentiated

Tc — Claron Formation

Mesozoic

CRETACEOUS

Ku — Cretaceous rocks undifferentiated; includes Kaiparowits and Tropic Formations and Straight Cliffs, Wahweap, and Dakota(?) Sandstones

JURASSIC

Jecu — Entrada Sandstone and Carmel Formation undifferentiated

Jc — Carmel Formation

TRIASSIC and TRIASSIC(?)

J̄n — Navajo Sandstone

R̄k — Kayenta Formation

R̄mo — Moenave Formation

R̄c — Chinle Formation

R̄s — Shinarump Member of Chinle Formation

R̄m — Moenkopi Formation

Paleozoic

PERMIAN

Pka — Kaibab Limestone

CAMBRIAN to PERMIAN

P̄zu — Palezoic rocks undifferentiated, includes Toroweap and Supai Formations, Coconino Sandstone, Callville and Redwall Limestones, Devonian to Cambrian limestones undifferentiated, Pioche Shale, and Prospect Mountain Quartzite

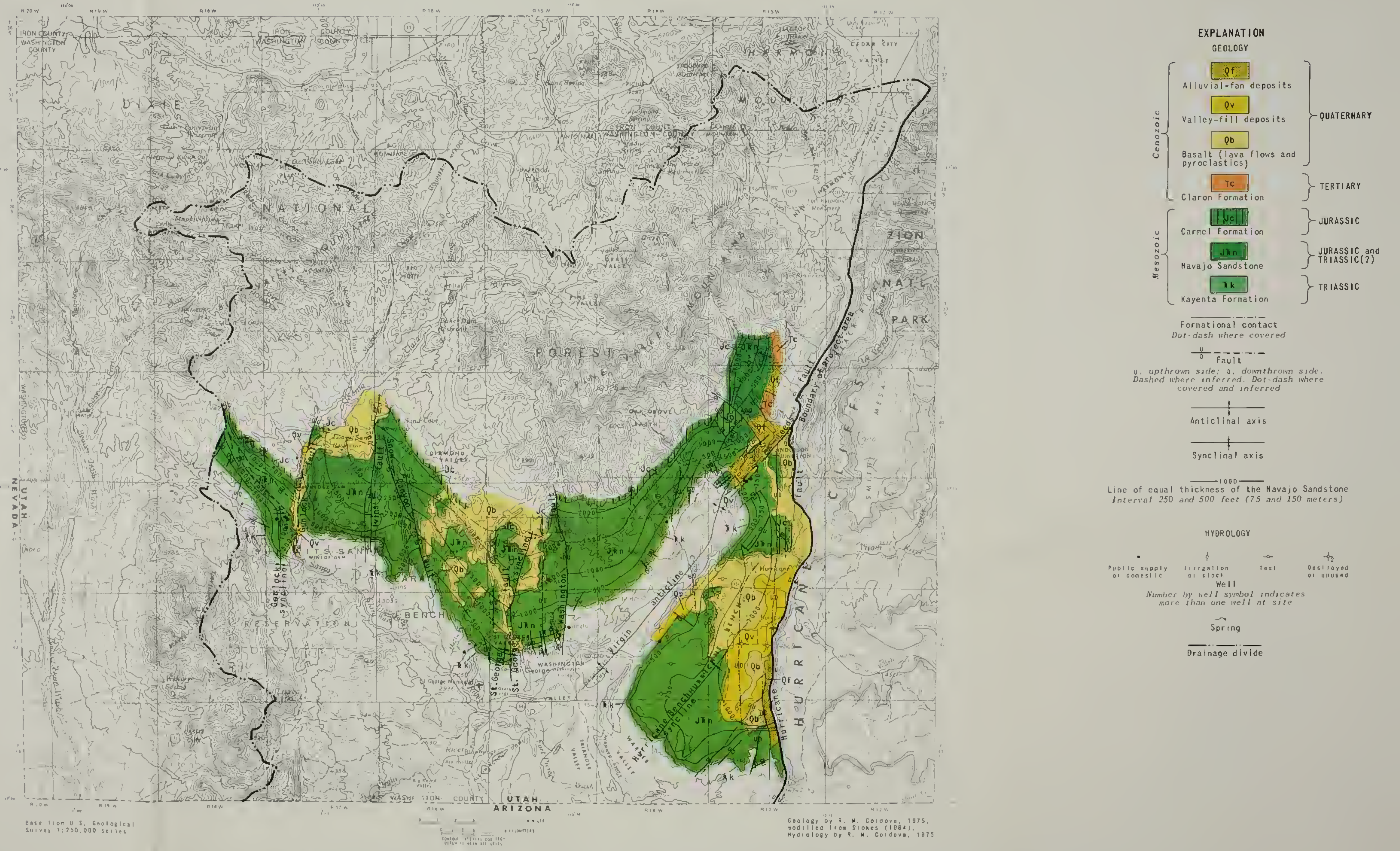
Contact

Fault
Dashed where inferred, dotted where concealed

——25——
Line of equal normal annual (1931-60) precipitation
Interval 4 and 5 inches (102 and 127 millimeters)

Drainage divide

MAP SHOWING THE GEOGRAPHIC AND GEOLOGIC SETTING OF THE NAVAJO SANDSTONE AND THE AREAL DISTRIBUTION OF PRECIPITATION IN THE CENTRAL VIRGIN RIVER BASIN, UTAH



MAP SHOWING THE LOCATION OF SELECTED DATA-COLLECTION SITES AND AREA OF OUT-CROP, GEOLOGIC STRUCTURE, AND GENERALIZED THICKNESS OF THE NAVAJO SANDSTONE IN THE CENTRAL VIRGIN RIVER BASIN, UTAH

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

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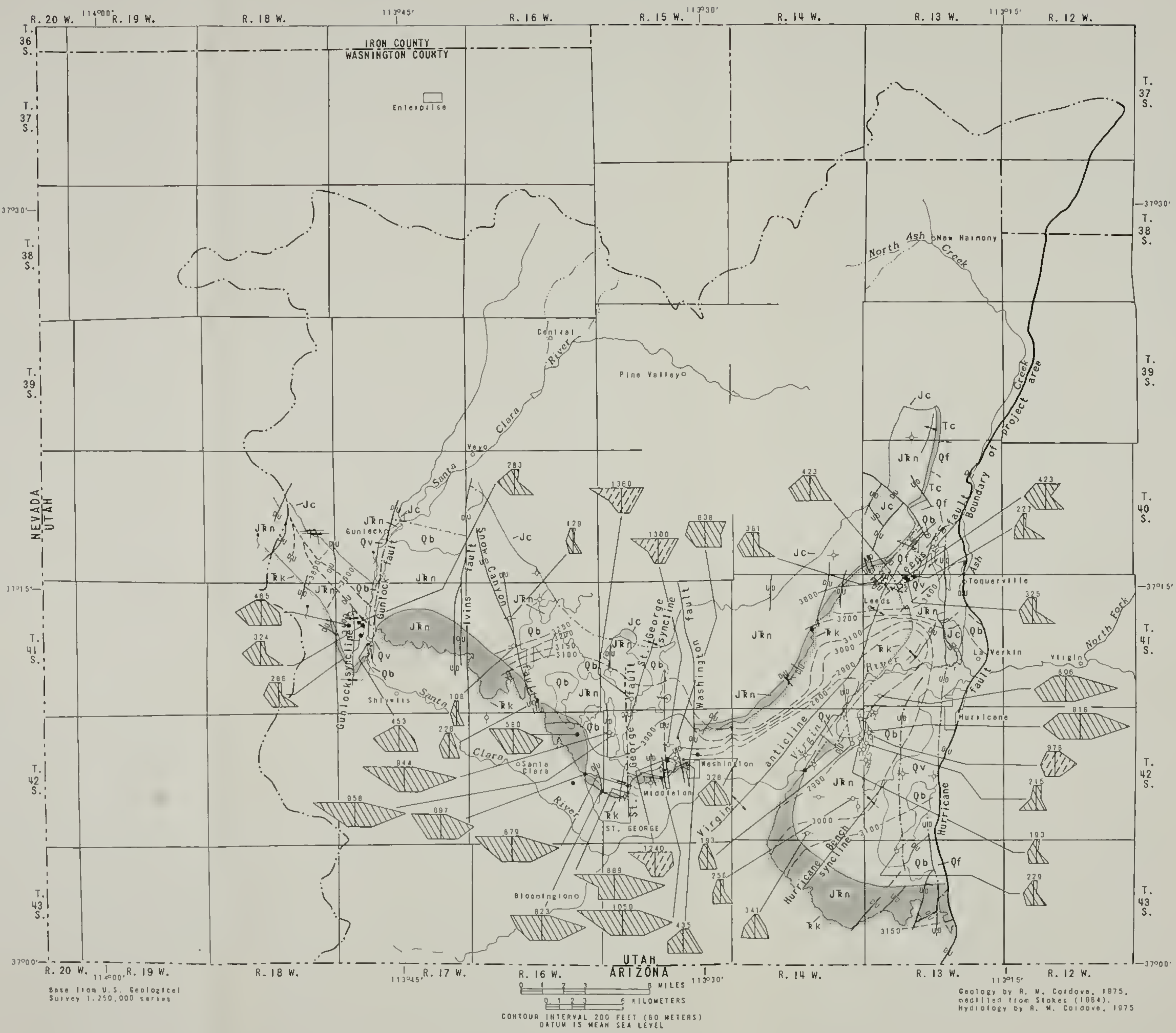

EXPLANATION

GEOLOGY

Cenozoic

- Qf — Alluvial-fan deposits — QUATERNARY
- Qv — Valley-fill deposits — QUATERNARY
- Qb — Basalt (lava flows and pyroclastics) — QUATERNARY
- Tc — Claron Formation — TERTIARY

Mesozoic

- Jc — Carmel Formation — JURASSIC
- J̄Rn — Navajo Sandstone — JURASSIC and TRIASSIC(?)
- R̄k — Kayenta Formation — TRIASSIC

Formational contact
Dot-dash where covered

Fault
U, upthrown side; D, downthrown side. Dashed where inferred. Dot-dash where covered and inferred

Anticlinal axis

Synclinal axis

HYDROLOGY

Public supply or domestic — Irrigation or stock — Test — Destroyed or unused

Well
Number by well symbol indicates more than one well at site

Spring

Water-level contour
Dashed where inferred. Contour interval 50, 100, and 200 feet (15, 30, and 60 meters). Datum is mean sea level

Approximate area of unsaturated Navajo Sandstone
Where the potentiometric surface is below the base

CHEMICAL QUALITY

Stiff diagram (after Stiff, Jr., 1951) showing amounts of major ions in solution

Sodium (Na) + potassium (K) — *Chloride (Cl)*
Calcium (Ca) — *Sulfate (SO_4)*
Magnesium (Mg) — *Bicarbonate (HCO_3) + carbonate (CO_3)*

MILLIEQUIVALENTS PER LITER
Compressed scale shown by dashed pattern

Number above diagram is dissolved solids, in milligrams per liter

Drainage divide

MAP SHOWING A GENERALIZED POTENTIOMETRIC SURFACE AND SELECTED CHEMICAL-QUALITY INFORMATION, CENTRAL VIRGIN RIVER BASIN, UTAH